INDICATOR
AND
DYNAMOMETER.

THE INDICATOR AND DYNAMOMETER,

WITH THEIR

PRACTICAL APPLICATIONS TO THE STEAM-ENGINE.

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FROM THE FOURTH LONDON EDITION. ILLUSTRATED.

PHILADELPHIA:
HENRY CAREY BAIRD & CO.,
INDUSTRIAL PUBLISHERS, BOOKSELLERS AND IMPORTERS,
810 WALNUT STREET.
1883.

INTRODUCTION.

THE object of the following pages is to extend the knowledge of two instruments connected with the Steam-engine, the Indicator and Dynamometer: the former of which is of universal application in land and marine engines; and the latter is applicable to those marine engines in which the screw is used as the means of propulsion.

The Indicator is one of Watt's inventions, upon which he was accustomed to place great reliance; and it may not, perhaps, be too much to say, that, in his hands, it contributed mainly to his successive improvements of the Steam-engine. After his patent had expired, and the Engine had become public property, the various makers, it seems, did not at first sufficiently value this useful instrument; for we find Farey, in his work on Steam, complaining that Steam-engines had rather retrograded from neglecting it. However that may be, such is not the case now; for every engine maker is careful to apply it, as the best means of testing the working condition of his engine; yet even now there are many classes of people connected with the Steam-engine, such as officers commanding steam-vessels and engineers, to whom a fuller description of the instrument, and the uses to which it may be applied, will be acceptable.

Having felt personally the want of more practical information on the subject in existing works, it has been thought by the Authors that the following pages will supply a deficiency, of which many have complained; and enable those who have not the opportunity of making experiments to gain a more intimate knowledge of the Indicator; and it is hoped that some novel applications of the instrument will at the same time give it a degree of interest among those who are conversant with its ordinary details.

CONTENTS

THE INDICATOR.

THE Indicator appears to fulfil two distinct and very important ends.

1. It enables us to discover whether there are any defects in those parts of the machinery by which the steam is admitted to the piston: for instance, it indicates whether the slides are properly set, or leaky; whether the stops on the intermediate shaft are properly placed; whether the steam-ports are large enough; and, consequently, whether a different arrangement of the working part of the machinery would be advisable. In fact, in the hands of a skilful engineer, the Indicator is as the stethoscope of the physician, revealing the secret workings of the inner system, and detecting minute derangements in the parts obscurely situated.

2. It discovers, at any instant of time, and under any given circumstances, when it may be desirable to apply it, what is the actual power of the engine.

We will first give a description of the instrument, and then proceed to its various uses.

Plate I. Fig. 1, is an external view of the Indicator, as constructed by Messrs. Maudslay and Field, having half the dimensions of the original in every respect. The dotted lines are intended to show the internal parts. *A* is a hollow cylinder, whose upper end *EH* is open; the lower end

being intended to fit into an orifice in some part of the engine (generally the top or bottom of the cylinder) by means of the screw *aa*; *b* is a stop-cock, by which, when the instrument is attached, we can, at will, make or cut off a communication with the internal parts of the engine. Within the hollow cylinder *A* is a piston *mn*, packed and fitting steam-tight.* Let us suppose, for perspicuity, the instrument to be in communication with the *top* of the steam-cylinder. Then, when a vacuum is formed above the steam-piston, the atmospheric pressure will force down the piston of the Indicator, and it will remain at its lowest position till fresh steam enters; but it would immediately (unless prevented), on receiving a new impulse, be blown out of the open top *HE*. To prevent this, and at the same time to enable us to measure the force of the steam, a spiral spring presses with its lower extremity against the surface of the piston, while its upper end rests against the fixed cross-piece *c*. By this arrangement, the place of the piston will always vary as the pressure of the steam varies; for it is a mechanical fact, that the tension of a spring varies as the extension. Hence the greater the pressure of the steam, the more the spring is compressed; and, on the contrary, as the steam loses its elastic force, the spring expands, and the piston descends. So that, to get a clear idea of the instrument, conceive the piston to be acted on by opposing forces: on the lower surface by the pressure of the steam (continually varying), and on the upper surface by two forces, viz., the pressure of the atmosphere (constant) and the force of the spring (varying so as to balance the steam-pressure). Now,

* In practice this piston must not be packed *overtight*, for fear of increasing the friction and preventing the free motion of the pencil; but the defect, if any, must be remedied by keeping melted tallow or oil on the upper surface.

as the steam-force is perpetually varying, it follows that the piston-tube (*de*) will be continually rising or falling. If a pencil (*p*) be attached to the upper end of this tube (*de*) in which the spring works, it will describe a vertical straight line on a piece of paper brought into contact with it. This, however, is not sufficient for our purpose. This line would, after it was traced, tell us the maximum and minimum pressure during the stroke: but the pressure *at any particular portion of the stroke* would still be undetermined. We must, therefore, have some plan similar to that adopted in other cases where the vertical motion of a pencil under particular circumstances is to be *registered.* In all such instances, the paper on which the variation is to be laid down is drawn horizontally at a certain rate. If, for instance, we were desirous of recording how the pressure varies with the *time*, the paper must be drawn *uniformly*, by connecting it with clock-work, or some other apparatus for giving a *uniform* motion. But this, however, is not usually the desideratum in the steam-engine. Our object is here to have, represented before our eyes, the variation of the pressure for every portion of the stroke of the piston; and this is contrived as follows: the paper is wrapped round a cylindrical barrel *C*, which is brought back against a stop, by a strong watch-spring contained in the box *EF*. A string passes round the pulley *D*, and is led away through a fair-leader *G*, to some part of the engine having a similar motion to the piston cross-head, only much reduced; by which means the watch-spring and the spring are always opposing each other. As the piston rises, the barrel will be pulled from left to right; and, on the contrary, as the piston descends, the string having a tendency to slacken, the barrel will, by the force of the spring, be brought back from right to left. At *p* is the pencil attached to the upper

end of the tube (*dg*), and rising and falling with the Indicator-piston; and this can be brought into contact with the paper on the barrel *C*, or removed from it, at will, by means of the joint at *g*. The rod *az*, and another one on the opposite side of the cylinder, serve as guides to the piston.

The Indicator-scale.

The paper is kept on the barrel by means of the strip of metal *hi*, on which are divisions representing the pressure of the steam. It will be seen that it is graduated throughout its whole length, beginning from zero, and proceeding upwards and downwards. Now this zero is the level at which the pencil stands when the instrument is unconnected with the steam-engine, and therefore acted on by the atmospheric pressure above and below the piston. The pencil will be seen at this level in the figure. If the barrel be made to revolve under these circumstances, a horizontal line will be traced out. This is called the atmospheric, or zero, line. And, therefore, the pencil will also be at this level whenever the steam, taking the place of the atmosphere *below* the piston, exerts the same pressure: and, consequently, wherever the diagram cuts this horizontal line, the pressure of the steam is 15 lbs. on the inch;* when on the level of the marks 1, 2, 3, etc., above this zero, the pressure is 16, 17, 18, etc.; and when on the level of the marks 1, 2, 3, etc., below this, the pressure is 14, 13, 12, etc.

To graduate the Indicator-scale.

Mark the point where the pencil touches the scale when the atmosphere is acting freely on both sides of the Indicator-piston; then, having previously found the area of the

* More strictly, 14·75 lbs, or a quantity differing from this slightly according to the state of the weather.

piston in square inches, multiply the result by 15, and apply it as a weight in lbs. to the under side of the piston. This will cause the pencil to descend through a space corresponding to a decrease in pressure of 15 lbs. Make another mark at the point where the pencil is standing, and divide the intervening space into 15 equal parts, each of which will correspond to 1 lb. pressure. This scale can be continued above the highest division as far as requisite. As an example, let us suppose the diameter of the piston to be $1\frac{5}{8}$ inch, the corresponding area is 5·1051 square inches, and the weight to be attached $15 \times 5{\cdot}1051$, or 76·5 lbs.

When the atmospheric line is to be traced.

The atmospheric line should not be taken till after the rest of the diagram has been completed; because, as the parts become warm by the steam, slight variations occur in its position, depending principally on the alteration in the force of the spring; and since this line serves as the origin from which the pressures are dated, it is necessary to have it laid down as correctly as possible.

The use of the small hole (m) in the side of the stop-cock (mb).

It serves to let the air into the cylinder (*A*) when the steam is cut off by the stop-cock, and thus enables us to take the atmospheric line; the stop-cock performs the office of a three-way cock; for by turning it in one direction we allow the steam to enter, and exclude the external air; and by turning it in the opposite direction we admit the air, and exclude the steam.

Method of taking a diagram.

First, look out for some part of the engine whose mo-

tion is proportioned to that of the steam-piston;* taking care that the space moved through at that part shall be somewhat less than the circumference of the traversing barrel;† that is to say, whatever be the diameter of the traversing barrel, let the movement of the part you are looking for be not greater than *three* times this diameter. Fasten a string firmly to this point, and have a traversing loop in the loose end of the string; it must be of such a length that it may be connected with the string passing round the pulley of the Indicator. Then close the stop-cock of the Indicator, and fix it by the screw (*aa*) to some orifice previously prepared in the top or bottom of the cylinder.‡ Insert the pencil you intend to use in the small hole (*p*) made for its reception, and clamp it there. The pencil should be hard, and have a fine point, to give as clear and distinct a line as possible. Those used for drawing-instruments, and marked HHH, are probably the best. Have some pieces of clean writing-paper provided, long enough to be brought round the traversing barrel, and overlap about an inch. Paper previously ruled is useful for this

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* That is to say, when you are wishing to find how the *pressure* varies with the *stroke* of the engine.

† In some engines there is no point except the cross-head of the piston to which the string could be attached. The motion must, in these cases, be reduced by pulleys; the circumference of one pulley being equal to the stroke of the engine, and that of the other to the motion of the Indicator, or they should be to each other in these proportions.

‡ If the top of the cylinder be chosen, the orifice for the grease-cup will generally answer the purpose. In most cases, however, a pipe leads from the top to the bottom of the steam-cylinder, and the Indicator is attached to this pipe. It is provided with stop-cocks, so that when once fixed, the arrangement is very convenient for taking two diagrams almost simultaneously from the upper and lower part of the cylinder. The only objection to it seems to consist in the tendency of the steam to condense in the pipe. For this reason it is advisable to have the Indicator as close to the cylinder as possible.

purpose, the ruled lines being placed lengthways on the cylinder. Wrap a piece smoothly round the barrel, and fix it by means of the clasp (*ih*) on which the scale is marked. Then tear away all the surplus paper, and examine what remains, to see if it be quite smooth; for if there be any ridges, the curve will have an irregular appearance, which might lead us to suppose some of the gear for working the slides had become loose, or much worn. Next wind the Indicator-string round the pulley of the barrel *D*; and connect the hook at its extremity with the loop of the string attached to the engine. Adjust the string by means of the running loop, till you are satisfied of the motion of the barrel; allowing it to make nearly a whole revolution, but examining it most carefully to see whether it becomes slack, or overtaut. The stop-cock (*b*) may now be opened wide, and the Indicator-piston will immediately start into motion; the piston must be well lubricated, to reduce the friction as much as possible, and at the same time to prevent leakage. Let the instrument work for a few seconds, to allow it to become thoroughly heated; and when it has arrived at the same temperature as the steam-cylinder, it is in a fit state to trace its diagram. When satisfied of the working of the machine, take hold of the pencil when it comes to the *bottom* of its stroke, as it is longer stationary at this part, and bring it gently into contact with the paper. This part of the operation requires some practice; for if the pencil be allowed to come forward too rapidly, the spring at *g*, by which it is pressed against the barrel, will break the point; and again, if held too long, the force of the steam, suddenly acting on the machine, will force it out of the hand, or break the holder. When left to itself, it will trace out a curve on the paper. As soon as it has made a complete circuit, let the pencil be withdrawn from

the paper (being careful not to take hold of it until at the *bottom* of its stroke). In order to have the line distinct, the pencil should not go over the same ground twice. Shut off the stop-cock, and the piston will become stationary, both sides being acted on by the pressure of the atmosphere. Bring the pencil again in contact with the paper, and as the barrel traverses, the atmospheric, or zero, line will be drawn. The operation is now complete, as far as the curve is concerned. Withdraw the pencil once more, unhook the line, and take off the traversing barrel. Next take a fine pointed hard pencil, and before taking the paper from the barrel, mark off upon it the scale of pounds, beginning with the atmospheric line, and proceeding upwards and downwards. After taking the paper from the barrel, it is completed by writing on it the date of the month, the name of the ship, that of the engine (whether starboard or port), top or bottom of cylinder (as the case may be), the number of revolutions, the pressure of steam by steam-gauge, and of condensation by barometer-gauge.

It is important to have means of shortening or lengthening the string attached to the Indicator.

Too much attention cannot be paid to this precaution. If an undue strain be brought upon the string it will stretch, and if the string be too long it will become slack; and in either case the barrel will be stationary for a small interval while the steam-piston is moving, and the curve will not be a true indication of the motion. Indeed, if proper attention be not paid to this point, the diagram may turn out very different from what it ought to be. The corners of the figure will be sharper and better defined, and consequently those little faults of the engine, which it is our object to discover, will be hidden.

The pressure of the steam and the state of the vacuum on the diagram do not correspond with the boiler-pressure and condenser-vacuum.

Both the steam-pressure and the vacuum will be less than that exhibited by the steam and condenser gauges respectively. The difference will depend on the size of the ports, the work the engine has to do, the distance the steam has to travel, the impediments it meets with in its passage from the boiler to the cylinder, and from the cylinder to the condenser.

The part of the engine to which the string should be attached.

It must not be attached to any part indiscriminately. Generally speaking, we wish to obtain the pressure of the steam for different portions of the stroke of the piston; therefore the string must be fastened to some part of the engine having a stroke proportioned to that of the piston, only much reduced. The part selected must be as near the Indicator as other circumstances will permit; for the greater the distance the longer the string, and consequently the greater is the chance of error from its stretching. Caution must be used also to prevent the string from slipping on the rod to which it is attached. One of the best contrivances for giving a free and proper motion to the string is to fix a pulley to the radius-shaft,* to the groove of which the fixed end of the string can be connected. It will be necessary, in other cases, to make use of fair-leaders for the purpose of conveying the motion from the part chosen to the Indicator; and due regard

* A quadrant will suffice, if a complete pulley cannot be fitted to the radius-shaft. In Maudslay's direct engine a pin can be fixed on the main centre of the air-pump beam. In Seaward's direct engine the string may be attached to the *centre line* of the radius-bar.

must be paid in placing fair-leaders, to ascertain whether the motion of the engine will be fairly represented by the Indicator.

On the general configuration of the diagram under given circumstances.

Let us bear in mind that all *vertical ascending* motions are caused by an *increasing* pressure of the steam, and that the *descent* of the pencil is a consequence of the elasticity becoming diminished. Again, with respect to the horizontal motion, we must first notice, that the pencil-mark is traced in a direction opposite to the motion of the cylinder-barrel, because the pencil is fixed in its socket, and the barrel moves beneath it. But as the barrel moves from right to left* (that is, as the pencil-mark is traced from left to right on the paper), the steam-piston is descending; while, on the contrary, as the pencil-mark proceeds from right to left, the piston is coming up.† We shall then arrive at the following general conclusions:

1. If the motion of the pencil be vertically upwards, as at 1, the steam-pressure is *increasing*, but the piston of the engine-cylinder is *not* moving. $\overset{1}{\uparrow}$

2. If the motion be downwards, as at 2, the steam-pressure is *decreasing*, but the piston *not* moving. $\underset{2}{\downarrow}$

3. If the line traced be horizontal, thus, $\xrightarrow{3}$ the steam-pressure *does not vary*, but the piston is *descending*.†

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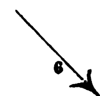
* The reader must imagine himself to be facing the Indicator-barrel, as in Fig. 1. (See Plate.)

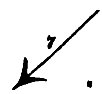
† This will be the case in one engine, but not necessarily so in another engine; and, moreover, if the string be led in another direction the reverse will happen; but this the practical man can correct for himself according to circumstances, and substitute *ascending* for *descending*, and *vice versâ*.

4. If the line be thus, $\xleftarrow{4}$, the steam-pressure *does not vary*, but the piston is *ascending.**

5. If the line run as at 5, the steam-pressurc is *increasing*, and the piston is *descending.**



6. If the line run as at 6, the pressure is *decreasing*, and the piston is *descending.**

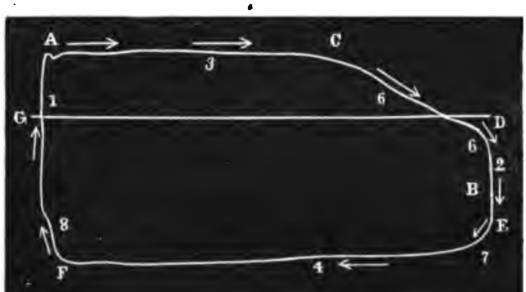


7. If the line run as at 7, the pressure is *decreasing*, and the piston *ascending.**

8. If the line run as at 8, the pressure is *increasing*, and the piston *ascending.**

The following diagram was taken from above the piston of H.M.S. *Bee;* and what follows will serve as explanation of it, and assist likewise in elucidating what has been before stated.

First, we will put numbers round the diagram, in conformity with the principles laid down in the last para-

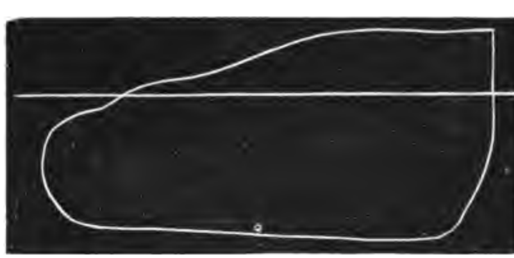


graph. Then, supposing the pencil to commence at *A*, and trace out the curve in the direction of the arrows, we

* See second note on preceding page.

see that the steam preserves its first and highest pressure for a considerable portion of the stroke, viz., from *A* to *C*; from *C* to *B* the downward stroke continues; but the steam begins to lose its pressure, although at a variable rate, decreasing rapidly at *D*. At *B* the motion of the piston ceases; but the steam continues to fall, till at length the pencil moves back nearly horizontally for some space, showing the pressure to continue invariable, although the piston is rising. At *F*, however, 8 shows the steam-pressure to increase rapidly and suddenly, the piston still ascending; till, as this oblique line merges into the vertical one at *G*, we perceive that the piston has arrived at the upper end of its stroke; and the fresh influx of steam drives the pencil up to *A*. From this point the pencil will retrace the same curve. *GD* is the atmospheric, or zero line.

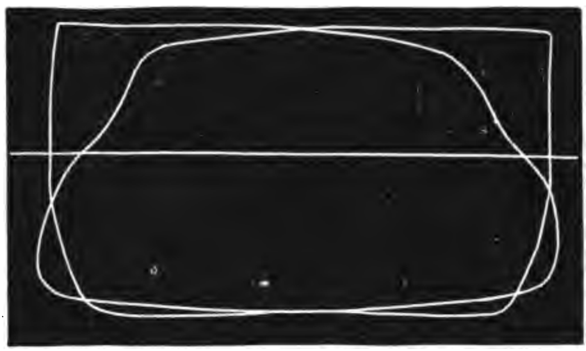
This diagram was taken from above the piston, and is usually called the "Top Diagram." Similarly, if we connect the Indicator with the bottom part of the cylinder, we shall get a diagram of the same nature, but all the motions will be reversed, as in the accompanying figure



Top and bottom diagrams exhibited on the same card.

It was stated in the foot-note of p. 10, that the Indicator may be attached to a pipe connected with the top and bot-

tom of the piston, and thus both diagrams may be taken on the same card without shifting the instrument. As this is the plan usually adopted at present, a specimen of the two diagrams is given, which will be as follows:



It will be observed that the two figures face each other, as they evidently ought to do.

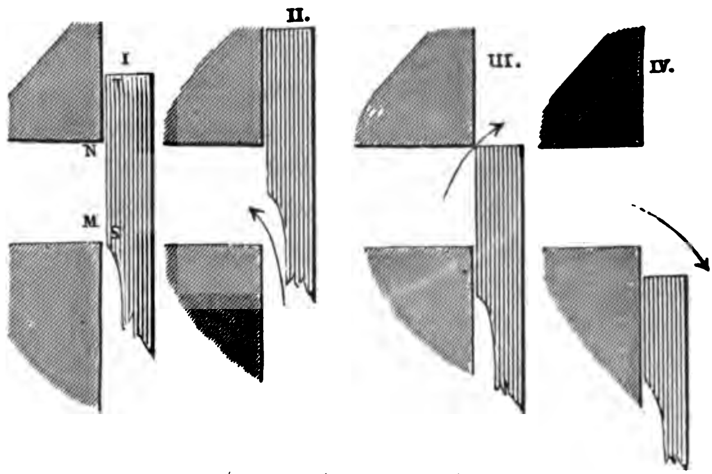
The above curves exhibit what has been going on within the engine.

The following drawings, marked I. II. III. IV., are intended to represent the upper steam-port of a steam-engine, with a section of the upper portion of the slide, in four different positions. In Fig. I., *MN* represents the portway, and *ST* the slide-face. The slide is supposed to be that commonly used in marine-engines, and called the Long D-Slide.*

When the pencil, in tracing out the diagram in p. 15, is at *G* (or it may be rather before arriving at *G*), the slide is in the position represented in Fig. I. and is rising;

* See *Marine Steam-Engine* (by the authors of this work), Article 125 (Long D-Slide).

so that the steam is about to enter the cylinder. Now this will take place, as the diagram shows, very slightly



before the upward stroke of the piston is accomplished; and since the piston and slide are both on the ascent, the lower edge *S* will have ascended a trifling space when the piston is at its highest. This slight space, though trifling in amount, is important in its results on the working of the engine. It is denominated the *lead* of the slide. As the piston descends, the valve continues to rise, and the admitting orifice becomes larger; so that although the piston is gaining speed in its downward course, yet in well-constructed engines the first pressure is continued, as we find in the diagram, through a considerable portion of the stroke.

The slide, however, has already begun its downward motion; and when the pencil arrives at *C*, it has returned into the position it had in Fig. I. It is clear that as it continues to descend, no more steam can be admitted; whatever the cylinder contains will remain pent up; and

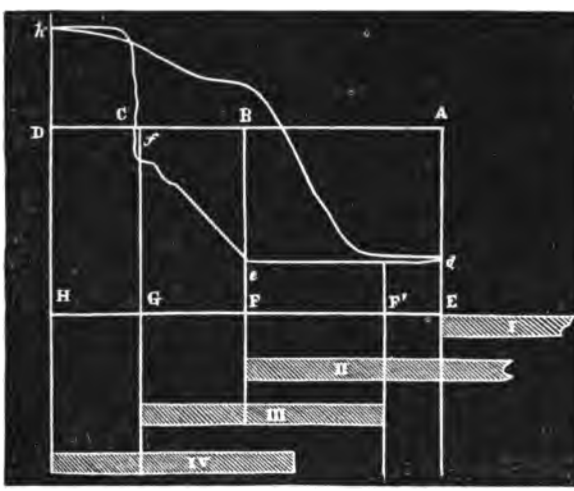
as the piston continues to move downwards, the steam relaxes its force, and we trace a corresponding depression in the diagram from *C* to *D*. But a still greater change is to be expected before the piston arrives at its lowest place. Ere that happens, the slide will have come into the position shown by Fig. III.: for it is found to be disadvantageous to allow the steam to be kept in the cylinder till the end of the stroke; because the entering steam at the reverse stroke would meet with so much opposition, till the vacuum on the opposite side had become tolerably good, that the equability of the motion would be much affected. This being granted, we see that the port will be open for eduction before the end of the stroke: consequently a rapid fall in the curve takes place at *D*. Moreover, the slide continues to fall, not only after the piston has come to the bottom, but evidently during the greater portion of the up-stroke: although, after a very short interval, from the great rate at which the steam rushes into a vacuum, the state of the vacuum is nearly unaltered, and but little different from that in the condenser; hence, after turning the right-hand corner, the pencil runs nearly horizontally. At *F*, however, the slide has returned to the position represented in Fig. III. and is *rising;* the piston is also rising and near the top; consequently the steam that has not yet made its escape, is pent up; and becoming more and more compressed, the pencil rises rapidly, till, the fresh steam entering, it starts up suddenly to *A*, and retraces the curve. A similar explanation will account for the bottom diagram.

The slide diagram.

This diagram is one in which the Indicator-string is connected with the cross-head *of the slide*, and not with that

of the piston; so that the horizontal motion of the pencil backwards and forwards corresponds to ascents and descents of the slide, and *vice versâ*. And this process will give us many particulars of the slide, without the trouble of taking the engine to pieces for measurement. If the Indicator be in connection with the upper end of the cylinder, it will give us information of the upper slide-face; and if with the lower end, of the lower slide-face. As was before stated, the string must be connected with some part having the motion of the slide; but generally it will be necessary to reduce the motion, because the stroke of the slide is more than the Indicator-barrel will allow; in small engines, such as that of the *Bee*, it may be attached to the cross-head direct. As was remarked, so long as the barrel is moving from left to right, the slide is rising; and when moving from right to left, it is falling; and any rise or fall of the pencilled line is due to the variation in the steam-pressure, as in the common diagram. The difference in the two cases, then, simply amounts to this: that in the common diagram we have changes of pressure corresponding to the motions of the *piston-rod*, and in the slide diagram we have changes of pressure corresponding to the motions of the *slide-rod*, the horizontal movement in both cases being similar; so that in reading off either a cylinder or a slide diagram, the laws of motion are precisely the same; and therefore, this once understood, there is no difficulty in reading or comparing both diagrams; and the important thing to notice is, that every sudden change of pressure refers to some prominent epoch in the slide's motion; and consequently we are enabled to trace successively on the paper the various positions of the slide from its lowest point as it cushions the steam, allows fresh ingress, etc., and finally arrives at its highest point.

Below is a slide diagram, obtained by connecting the string to the slide cross-head of the engine of H. M. S. *Bee.** The whole length of the figure is the same as the travel of the slide. If not, a method must be adopted to be afterwards explained. When the pencil is at *d*, the slide is at the lowest point, and the vacuum is very good, as the slide rises till the pencil comes to *e*; but since we know *à priori*, that the vacuum remains good in the engine till the cushioning commences, therefore when the slide has risen from *d* to *e*, the cushioning commences,



and continues as the slide rises till the pencil arrives at *f*, when fresh steam enters, and after this epoch the slide still rises till the pencil has reached the point *h*. As the upper line is not so marked in its character as the lower one, we shall not say any thing of the downward stroke.

* The reader will perceive that in this diagram the steam is of higher pressure than that in p. 15. This is caused by a new boiler having been introduced into the vessel, which is loaded to 10 lbs.

Through the points d, e, f, etc., draw the vertical lines Ad, Be, Cf, Dh, cutting the atmospheric line in A, B, C, D, and the horizontal line EH in E, F, G, H. Suppose EH to be the nozzle of the steam-port, on which the face of the steam-slide moves (the cylinder being for convenience of illustration supposed to be lying *horizontally*). Then, since when the pencil comes to e the cushioning commences, F must be the upper edge of the port. Take FF' equal to the depth of the port (which we will suppose known). Again, since when the pencil is at d the slide is at the lowest, therefore we must suppose it to have started from E; and consequently, at starting, the upper edge of the slide was below the lower edge of the port, the space $F'E$. When the *upper* edge of the slide arrives at G, fresh steam enters; in other words, the lower edge of the port is at F', and therefore the depth of the slide-face is $F'G$. Moreover, since the slide still rises through the space HG, HG will be the greatest amount of opening for steam. The successive positions here spoken of are laid down in the figures under the line EH. FF' is the depth of the port. In 1, the slide is at its lowest; in 2, the cushioning is commencing; in 3, the steam is about to enter; in 4, the slide is at its highest.

To reduce the motion of the slide when too great.

When the travel of the slide is greater or less than the breadth of the diagram, let HE be the breadth of the diagram, as in the last paragraph; from H draw HP, making any finite angle with HE, and equal to the travel of the slide. Join PE, and through F and G draw FQ, GR, parallel to EP, and then proceed with the line HP, as in

the last paragraph with the line HE, considering Q to be the upper edge of the steam-port, etc.

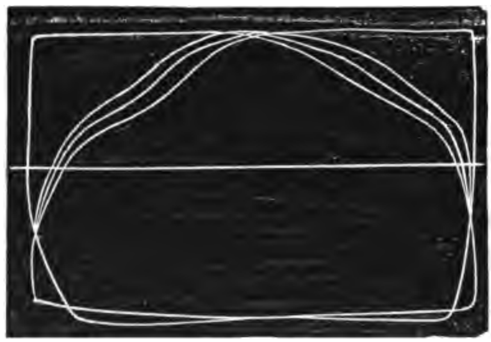
To explain how an alteration in the length of the gab-lever affects the diagrams.

If the gab-lever be shortened, the travel of the slide will be increased, but the whole motion will occupy the same time. Now to see the effect of this on the opening and closing of the steam-ports, we will suppose the slide in the middle of its stroke, as in Fig. III. p. 18, and rising to admit steam to the upper port. Then, since the space through which the slide has to move in a given time is increased, it will allow the steam to enter, by assuming the position which it has in Fig. I. p. 18, earlier than it would have done without the alteration. Also, it follows that the remaining portion of the upward motion will not occupy a longer time, but that the greatest opening for steam will be increased. Conversely, as the slide goes down again, it will take a longer time before the steam is excluded. Now since the slide is in the middle of its motion about the

same time in both cases, the cushioning will commence nearly at the same time; but because fresh steam enters earlier, the lead will be increased; and because the maximum opening is increased, the steam-line will be improved and it will be carried further along, for the admission of steam ceases at a later period; finally, the opening to the condenser taking place about the middle of the slide's stroke, it will be unaffected by the alteration. The same reasoning will show that the vacuum-line is also improved. This explanation is exemplified in the following figure,

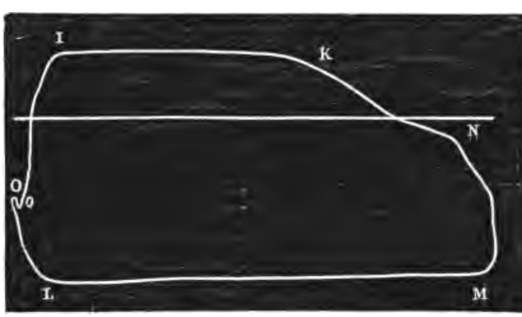
which consists of two diagrams, the outer one being that in which the gab-lever had been shortened, and the inner one was obtained by lengthening the gab-lever. A similar alteration will take place in the bottom diagram. The figure in the next page represents three top and three bottom diagrams. The middle one of each represents the normal diagram; the two outside ones those which were taken after the gab-lever had been shortened; and the two inner ones those taken after the gab-lever had been lengthened. It will be seen by this figure, that if any advantage be gained in the top diagram by altering the length of the gab-lever, the same advantage will be gained in the bottom diagram. If therefore it be found that the steam be wire-

drawn at *both* ports and there be too little lead, both diagrams will be improved by shortening the gab-lever.



To explain why the accompanying diagram has a different outline from the standard diagram in p. 15.

We observe, in the first place, that the steam-line, *IK*,



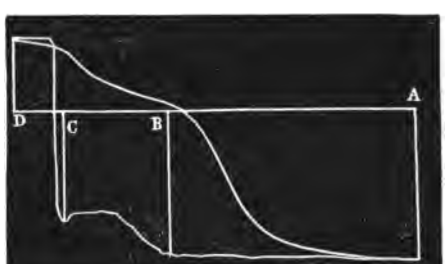
is shorter than in p. 15, while the exhaust line, *LM*, is longer than in the latter; we infer, therefore, that the steam had a shorter time to come into the cylinder, and a longer time to make its escape. We observe, likewise, that the engine had made a considerable portion of its downward stroke before fresh steam was admitted.* Now

* We see in the upper left-hand corner of this diagram the motion marked 5 in p. 15, which does not appear in the normal diagram.

these phenomena can be explained, by supposing from some cause the slide to be removed bodily below the place it had when the former diagram was traced. For let us refer to the series of representations of the slide before noticed. Thus the point *I* shows us the steam comes in later in this diagram than in the former; and the valve is rising; consequently its lower edge will be at some point lower than it would be in ordinary circumstances. Again, the point *K* of the diagram indicates to us that the steam is cut off again sooner; but the slide is descending; and therefore, also, the lower edge is lower than it ought to be. Again, *N* being too far from the end of the stroke, we see that the exhaust takes place too early; in other words, the upper edge of the slide is too low. And lastly, the point *L* (where the cushioning commences) being carried too far to the left, shows us that too great an interval elapses before the upper edge of the slide reaches the upper edge of the port. And, consequently, every part of the reasoning proves to us the fact, that the slide is lower than should have been the case. Now, in pursuing our inquiries, we shall find this is caused by one of two defects, viz.: *either the slide-rod is too long, or the eccentric-rod is not of the proper length.* But in seeking for the remedy, we must look to *the slide rod alone*, because its length can be more easily adjusted than the eccentric-rod, by means of the nuts and screw by which it is fastened to the cross-head. The derangement of the engine, when the accompanying diagram was taken, was obtained by *lengthening the slide-rod three-eighths of an inch.* The projection at the point *O* remains to be noticed, although it would not appear, except in exaggerated cases, such as the one before us. It will be seen that the cushioning takes place from *L* to *O*; and consequently the pencil rises, because the steam

is compressed: but the fresh steam does not yet enter; and therefore, as the piston descends, this steam, till now compressed, loses its elastic force, and the pencil drops; till at *o* a fresh supply enters, and the pencil starts up from *o* to *I*, taking a motion compounded of the motion of the piston and the pressure of the steam; for it is to be noticed that the line *oI* bends sensibly to the right; this arises from the increasing velocity of the piston, and is not observable in the standard diagram, except near the top, because the piston is all but stationary during the short time the steam is entering.

The slide diagram also affords great facilities in discovering disarrangements of those parts of the engine whose office it is to permit the entrance and egress of the steam, because since at those particular times the motion of the piston is so slow, nothing definite can be ascertained. The accompanying diagram was taken while the slide was too low in the casing, on account of the lengthening of the rod.

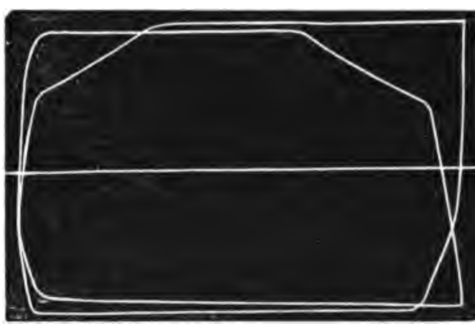


Now since *DC* is the amount by which the port is opened for steam, we should expect this to be smaller than in the *standard* slide diagram, p. 22, and on comparing them we find this to be the case. Also the space *BA*, or the amount of travel of the slide before the communication with the

condenser is cut off, is greater than in the standard figure. In all cases BC will be constant.

Top and bottom diagrams with the slide-rod lengthened.

If both diagrams are taken on the same card, the accompanying figure will represent each. The left hand one will give the steam and vacuum lines on the upper side of the piston, and the right-hand one the same on the lower side of the piston; and it will be observed that the former is contracted above and spread out at the lower part, while the opposite effects take place in the other.

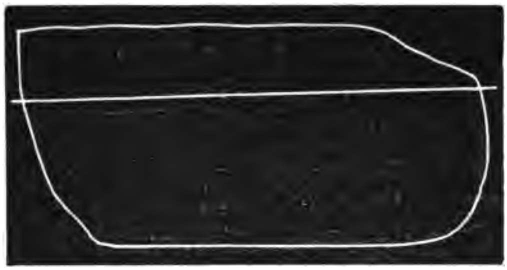


To find the nature of the curve, if the slide-rod be shortened.

The opposite effects to those mentioned in p. 26 will take place; that is to say, the upper portion of the diagram will be spread out, and the lower part contracted. The effect is shown in the diagram in next page, to obtain which the *slide-rod was shortened three-eighths of an inch.*

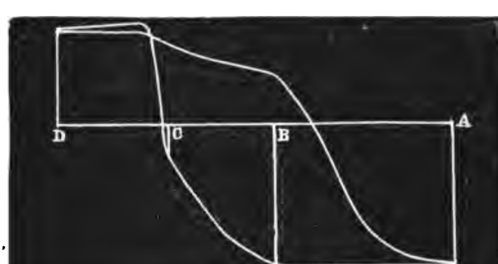
NOTE. If the *whole* slide be of the proper length, it is clear that when we get a faulty diagram, similar to that in p. 25, taken from above the piston, the one taken from beneath it will be similar to the annexed figure, and *vice versâ.* Hence, therefore, we see one advantage of taking both a top and bottom diagram. But if the one diagram

be similar to one of those just exhibited, and the other be satisfactory, the fault lies with the slide itself, and cannot



be remedied except by the engine-makers; for the slide-faces are not permitted to be cut away or added to without the sanction of those who are responsible for the ship. The only plan the engineer can adopt is, to divide the fault as equally as he can between the upper and lower parts, by lengthening or shortening the rod, according to circumstances. Moreover, we perceive an engineer should not be satisfied that he has done all, when he has obtained a good diagram from one end of the cylinder; because, if the fault lie with the slide, he will be improving one to the injury of the other.

The slide diagram which is given below shows very

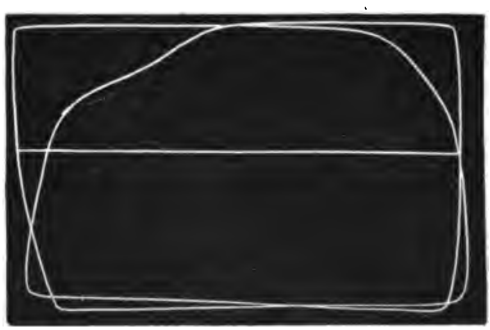


clearly that the slide had been raised above the position it had when the diagram in p. 22 was described. For

D C (or the amount of opening for steam) is here increased, and *A B* is diminished; *B C* remaining constant as before. Comparing the form of this diagram likewise with that in p. 27, we see they are very dissimilar, especially in that part of the lower curve lying between *B* and *C*. The steam-piston evidently comes to the top of its stroke about half-way between *B* and *C*, and in the diagram, p. 27, it is observable by the downward course of the curve that fresh steam is not admitted till the piston has descended some small space. But this peculiarity is not to be seen in the above figure, because the cushioning and lead are blended together.

Top and bottom diagrams with the slide-rod shortened.

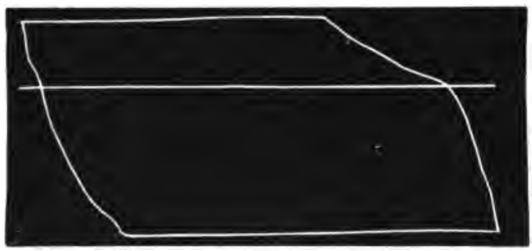
In this diagram the left-hand figure is spread out on the steam-line and contracted in the vacuum-line, while the opposite effects take place in the other.



The effecton the diagram, if the stop on the eccentric be too far advanced.

All the motions of the slide, whether up or down, take place sooner than ordinary: that is to say, the cushioning, the introduction of fresh steam, the cutting off, and the exhaust, all commence sooner. The curve, therefore, in-

stead of being like the *standard diagram* (p. 15), will assume somewhat of a lozenge-shape, the upper left and lower right corners being acute-angled, and the other

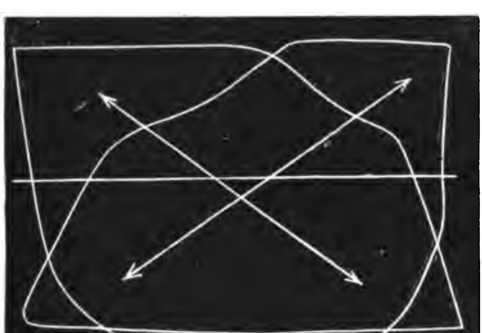


two obtuse, as in the above diagram. Again, a little reflection will enable us to discover that *similar* defects will be exhibited in the lower diagram under these circumstances, and not *opposite* defects, as was the case when the slide or eccentric-rod was at fault.

OBS. This curve was obtained by inserting a piece of iron, half an inch thick, between the stop on the eccentric and that on the shaft.

Top and bottom diagrams with the eccentric stop advanced.

Since similar effects take place here under these circum-



stances, the two curves will be similar and facing each

other, and will be represented by the foregoing diagram.

To ascertain, by inspecting the diagram, if the stop on the shaft be not sufficiently advanced.

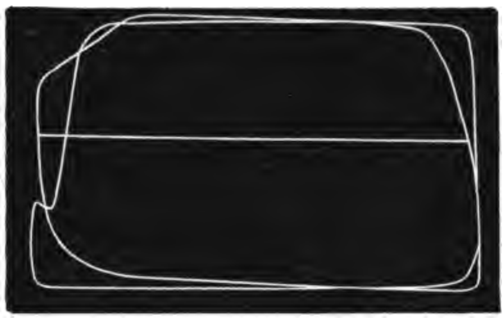
If the stop be not sufficiently advanced, all the motions of the slide will be later than they would be in a well-constructed engine; consequently, all the upper part of the curve will be drawn towards the right, and all the lower part to the left. And, as in the former case, the same distortion will be observable if a diagram be taken from the lower part of the cylinder. Morever, if the defect be great, we shall meet with the hump in the lower left-hand corner, similar to that before noticed. The following diagram was taken after removing back the stop on the shaft seven-sixteenths of an inch.*

Top and bottom diagrams with stop of eccentric put back.

From what has been previously stated, the reader will

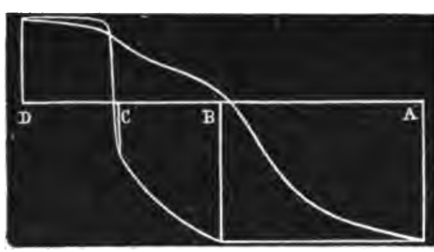
* The stop of one engine may be put back with advantage if the other engine be disabled; for by so doing it will be assisted in turning its centres, from the steam being carried farther over the diagram.

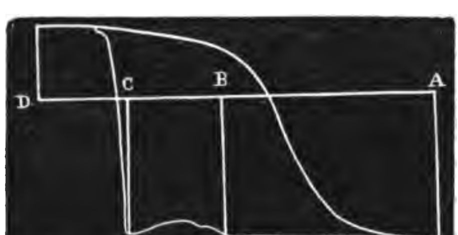
see that the accompanying diagram will correctly represent this case.



Slide diagrams with eccentric stop wrongly placed.

The two following curves represent respectively the *slide* diagrams taken when the stop was advanced and put back



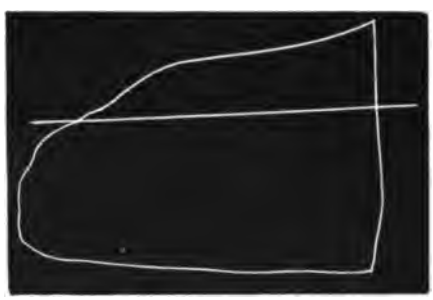


respectively; and the spaces *AB*, *BC*, *CD*, in each of these are the same as in the standard figure, p. 22, the

only difference being in the *form* of the curves arising from the altered position of the piston relatively to the slide.

The nature of the diagram when the portways of the cylinder or the steam-pipe are too small for the size of the cylinder and the speed of the piston.

Since the steam will not be able to enter or escape so freely as it ought, the pressure at first entrance will not be maintained for any length of time, and the vacuum will not be formed rapidly enough; the steam and vacuum lines will therefore lose their horizontality; as is readily perceived in the diagram here given, which was taken from



one of our large engines, afterwards improved by shortening the gab-lever.*

Diagram obtained when the steam is throttled.

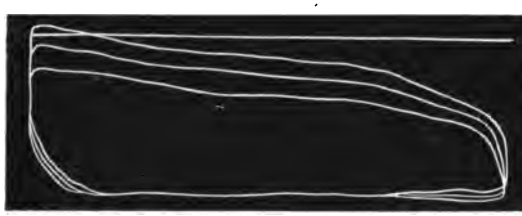
The upper line will rapidly decline, for the same reason that it would if the steam-pipe or the port were too small; and it will not be so high altogether as in ordinary cases. The vacuum-line, however, will be better than it would

* The reader will observe that this diagram differs from the preceding top diagrams by being turned end for end; but this depends on the way in which the string is led to the engine, and need not be noticed.

otherwise be; for since the quantity of steam admitted is not so great, the speed of the piston will be reduced. But the exhaust-port is of the same size whether the steam be throttled or not; and therefore there is more time for the expanded steam to rush through this orifice into the condenser; and consequently the vacuum-pressure in the condenser and in the cylinder will be more nearly equal, and better in both, than when the full power is set on.

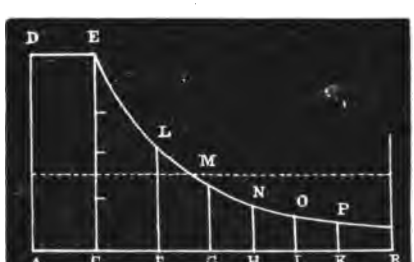
NOTE. When the pressure declines throughout the stroke of the engine, as it does in the foregoing diagram, on account of the contraction of the admitting orifice, the steam is said to be "wire-drawn."

The accompanying diagram represents three diagrams taken from the *Bee's* engine, the steam being throttled to various degrees.

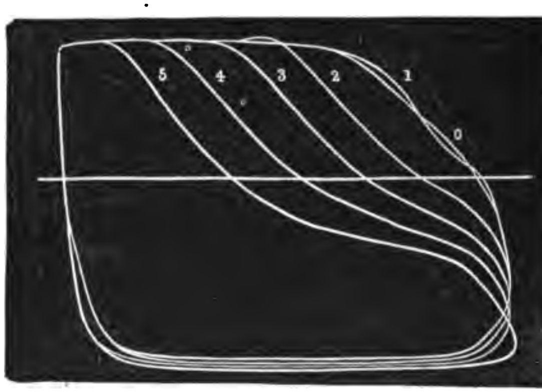


On the form of the diagram when the expansive gear alone is used.

Let AB represent the whole length of the cylinder; and



when the piston has traversed the space *AC*, let the ingress of the steam be suddenly stopped. Then, from this epoch, the steam-pressure will decrease, and the pencil begin to descend. Now if the temperature of the steam be unaltered, the pressure will vary inversely as the space it occupies. Divide, therefore, the space *CB* into intervals *CF*, *FG*, etc., each equal to *AC*; and therefore when the piston is at *F*, the space *AF* being *twice AC*, the pressure of the steam at *F* is *half* that at *C*; at *G* it will be one-third; at *H* one-fourth, etc.; and if lines be drawn through *C*, *F*, *G*, etc., parallel to *AD*, and of the length we have just indicated, making $CE = AD$, $FL =$ half AD, etc., and through the upper extremities of these lines a free curve *LMN*, etc., be traced, it will give us an idea of what we ought to expect. But since the slide-valve also acts, we

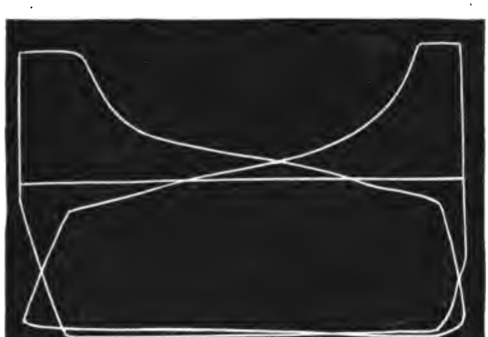


shall have the modification this would produce too; for the slide-valve is placed between the expansive-valve and the cylinder; it follows, therefore, that the effective volume of the steam intercepted by the expansion-valve is the whole of the space between it and the piston, and the slide-valve interposes an additional barrier when it begins

to cut off the steam.* The case, therefore, is somewhat similar to what it would be if there were two expansion-valves, one nearer to the cylinder than the other, and the outer one acting first. This figure exhibits a series of diagrams representing various grades of expansion: here 0 gives the full power of the steam without using the expansion gear; 1, that produced by the first grade of expansion; 2, that produced by the second grade; and so on. It is worthy of remark, that the diagram marked 0, which is that resulting from the slide-valve, closely assimilates to that marked 1, produced by the first grade of expansion, as it should do in well-constructed engines.

Top and bottom diagrams when working expansively.

The two curves will face each other, as in the former cases, and will be represented by the accompanying diagram where the highest grade of expansion is used.



The above expansion-diagrams, taken from above and below the piston when working on a high grade of expansion, serve to show the amount of disturbance in the

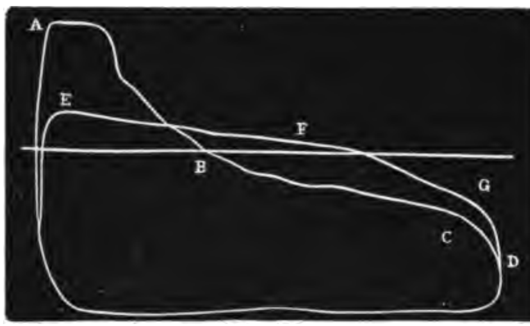
* Except in engines fitted with Seaward's slides.

steam-line of the two diagrams which is due to the obliquity of the connecting-rod; and they are of great value in that respect, because they show what error is due to that cause alone; whereas in the diagrams exhibited in pp. 16, 17, and explained in p. 45, the effect is due partly to the connecting-rod and partly to the same cause acting through the eccentric-rod. Now, in the case of expansive working, the action of the eccentric-rod is superseded by a cam, which shuts the expansion-valve at a certain period of the rotation, both in the up and down stroke; or, in other words, the valve will close when the crank makes the same angle with the vertical line, both in the up and down stroke; and since, by inspecting the above diagrams, we see that a greater portion of the stroke has been performed in the one case than in the other, this shows most convincingly the influence which the obliquity of the connecting-rod exerts in disturbing the diagram.

To show the advantage of expansive working over throttling.

The advantage gained will depend on the quantity of steam required to produce a given effect, or on the effect produced by a given quantity of steam. Let us, therefore, consider each of these cases separately; and first, taking the effect to be the same, let us compare the quantities of steam. Now the effect will be the same if the number of revolutions be the same. Let, then, in the first place, a diagram, such as *ABCD*, be taken when using the expansion cam; and let the number of revolutions be counted, which in this instance was 24. Then, instead of using the expansion gear, let the throttle-valve be partially closed till the number of revolutions be the same as before, viz., 24; then take a diagram such as *EFGD*. Now we remark that the quantity of steam used during

each stroke may be estimated by the heights of the curves at the points *C* and *G*, where the eduction takes place; because these heights exhibit the final pressure, and consequently will give us some idea of the amount. Therefore, because the diagrams show that the engine consumes

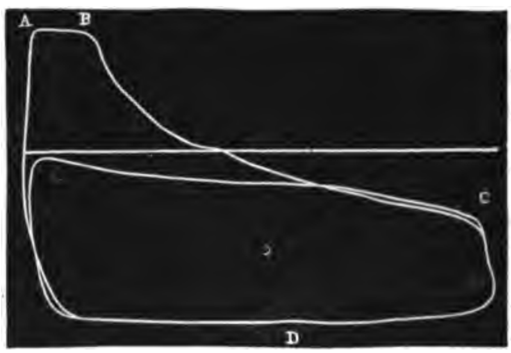


a cylinderful of steam of *greater* pressure when the steam is throttled than when working expansively, it must have consumed a greater quantity; and since the number of revolutions of the engine is the same as before, it follows that the work done is the same. We come, therefore, to the conclusion, that, in order to do the same work, an engine will require less steam when working expansively than when using the throttle-valve.

Next, after the expansion diagram has been taken, let the throttle-valve be partially and gradually closed, till the points *C* and *G* (of the former diagram) coincide, as in the following curves.* Then the final pressure of steam, and therefore the quantity expended for each stroke of the

* Some care will be requisite to effect this. The readiest plan is to cut to a point the end of the pencil which does *not* contain lead, and having inserted it in the instrument, trace out with it a *blind* curve on the paper, and when we see this curve coincide with the other, we may change ends with the pencil, and trace out the throttle curve.

engine, will be the same: but it was found on making the trial that the number of revolutions with the expansion curve being 24, the number was only 19·6 when the other curve was traced. Now, although it may be argued that the number of revolutions being different the quantity

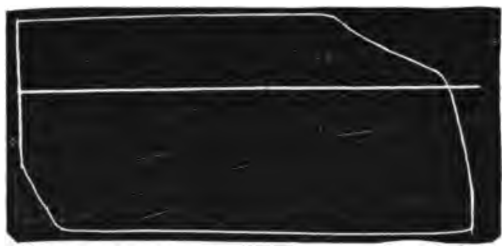


of steam used in a given time will not be the same, yet as there is such an excess of preponderance in the revolutions when working expansively, we may safely conclude that, if the same amount of steam in a given time had been used, the revolutions, and therefore the work done, by expansion would have exceeded that done by throttling.

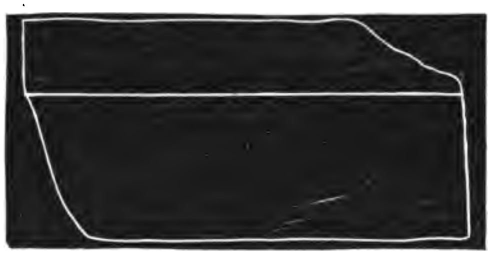
The general outline of the diagram may appear satisfactory notwithstanding the engine is not in good working order.

This may happen, because in the hands of an inexperienced person the Indicator may trace an unfaithful representation of the condition of the engine. When the piston is near one end of its stroke, if an undue strain be brought on the string, it will stretch, and the Indicator-barrel remaining stationary while the steam is entering the pencil will have a vertical ascending motion, such as is

represented in the figure. On the other hand, if the barrel come back against its stop before the opposite stroke is



accomplished, the pencil will fall vertically, as in the next figure. These two figures ought to have been precisely



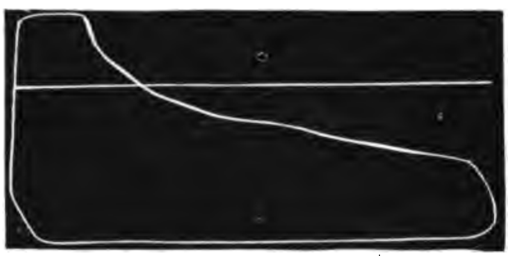
similar, the only cause of difference being the accident of the string.

On the series of steps in the upper right-hand corner of the accompanying diagram.

These arise from the piston of the Indicator being packed over-tight, on which account it descends by a series of jerks, as the steam-pressure relaxes.

To explain why, in certain cases, the steam-line (when the expansion gear is used) does not descend so rapidly as in the theoretical curve traced in p. 35.

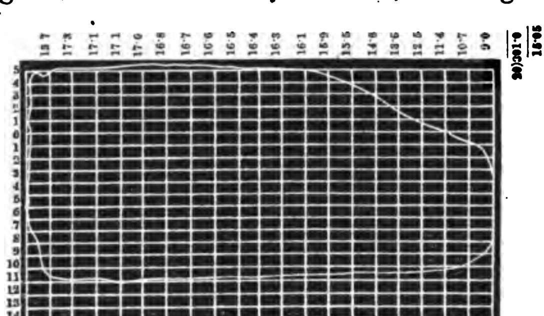
This will be the case whenever the expansion-valve is leaky, as it was when the accompanying diagram was taken.



As, for instance, in all cases where the common throttle-valve is used for an expansion-valve.

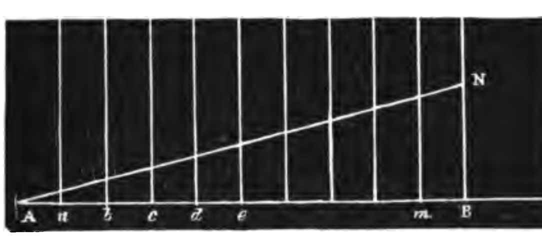
To ascertain the horse-power of an engine by means of the Indicator.

This is the only accurate way of ascertaining the power of an engine; because, as may be seen, the diagram gives



the pressure on the piston; and hence, knowing the number of revolutions and the length of stroke, the laboring force can be ascertained. The mean pressure on the piston is obtained as follows: Divide the diagram by a series of equidistant vertical lines, as in the figure* (the closer the better, where great accuracy is required), and, taking the horizontal line marked 0 as the origin, draw a series of other lines parallel to it at distances equal to the intervals corresponding to the scale of pounds on the Indicator. This being accomplished, if our object be only to form an estimate of the gross power, observe in the middle of each vertical space the number of pounds included between the steam and vacuum lines to tenths, which will be best done by taking the distance with a pair of compasses, and setting it off on the scale of pounds. Write these in their

* Since it is a difficult geometrical operation to divide a line into a great number of equal parts with any thing like accuracy, the following method may be useful in expediting this part of the work, by means of a scale. The scale consists of a line, such as *AN*, somewhat longer than the line *AB*, which is to be divided. Let this scale be divided into the requisite



number of equal parts, as in the figure. Fix one end at *A*, and turn it round that point till the other extremity *N* coincides with the line *NB*, drawn through *B* at right angles to *AB*. Then through the several points of division of *AN* draw lines, parallel to *NB*, cutting *AB* in the points *a*, *b*, *c*, *d*; which will be the points of division required. To those who are frequently in the habit of computing the horse-power of engines from the diagrams, this method will be found very advantageous.

proper columns, as in the figure, along the diagram, and add them together Then divide the gross result by the number of columns, and we obtain the gross average pressure on the one side of the piston during the up and down stroke. From this it is usual to deduct from 1 lb. to 1·5 lbs., according to the size of the engine, for friction; for small engines have more friction in proportion than larger ones; then the result is taken as the effective pressure per square inch, acting *uniformly* during one whole revolution. Take now the diameter of the cylinder in inches, and square it; then multiply the product by ·7854, the result is the number of square inches in the surface of the piston. Multiply this again by the pressure per square inch, as got from the Indicator, for the whole pressure in pounds on the surface of the piston. And if this be multiplied by the length of a double stroke, and finally by the number of revolutions, we shall obtain the work done by the engine. It is usual to divide this quantity by 33,000 (supposing this to be the number of pounds a horse would be able to raise one foot a minute); and the quotient is then called the horse-power of the engine. If there be two engines, as is usually the case in steamers, this quantity must be doubled. (See note, p. 45.)

Where accuracy is required, a diagram should be taken from the top and bottom of the cylinder.

The diagram taken from the top of the cylinder shows only the pressure and vacuum on the upper side of the piston, and therefore cannot indicate what is going on below the piston. If our object be merely to calculate approximately the horse-power of the engine, and it be in tolerably good working condition, it is not of much consequence whether the diagram be taken from above or be-

low; but if the horse-power is required with any great accuracy, the mean result obtained from the top and bottom diagrams must be used. If the actual state of the engine be required, it is necessary to examine into what is passing both above and below the piston, because the errors in one part may have no connection with the errors in another. This will be the case if the slide is too long or too short; in which case the upper port may be properly covered, and the lower one not so; or the upper slide-face may be steam-tight, and the lower one leaky: but if the Indicator be applied to top and bottom, it will detect all

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NOTE. *Ex.* In the preceding diagram, let the number of revolutions be 38, and therefore the number of single strokes 76.

Then, since diameter of steam-cylinder = 20 inches,

∴ $\text{Diam.}^2 = 400$
$.7854$

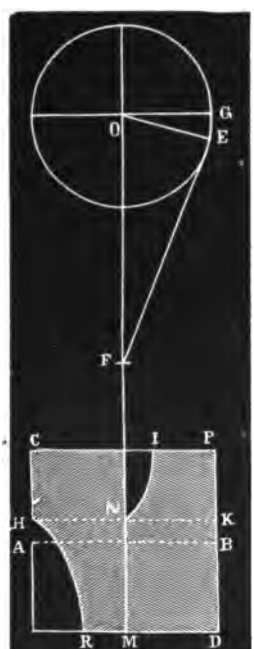
Area = 314·2000 sq. inches. (See table at end of this work.)

But pressure of steam by diagram	= 15·05lbs. (with old boiler.)
Deduction for friction	= 1·50
∴ Effective pressure per inch	= 13·55
Square inch in piston	= 314·2
	2710
	5420
	1355
	4065
Pressure in lbs. on piston	= 4257·410
Length of double stroke	= 4
	17029·64
No. of revolutions	= 38
	13623712
	5108892
	33|000)647|126·32
	$19\frac{2}{3}$ horse-power.

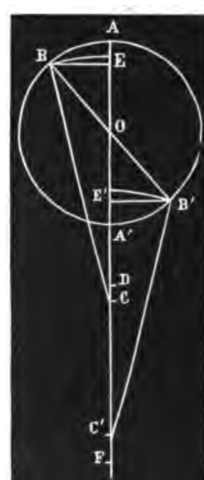
The horse-power is now nearly double this amount, because the evaporative power of the boiler has been increased.

these inaccuracies, and prevent our attempting to improve the working of one side to the detriment of the other. It ought to be remarked here, that in direct-action engines the diagram from below the piston is generally superior to the other. First, because, since the steam has more work to accomplish, the piston does not run away from the steam so readily, and in consequence the steam-pressure is better maintained; and there is generally a little more lead to the slide, to allow a freer ingress to the steam.

There is also another reason why the one diagram is frequently better than the other. If the reader will inspect the various top and bottom diagrams previously given, he will perceive that the former is always superior to the latter. It is invariably the case with the side-lever engines, or engines in which the motion is transmitted to the crank in an indirect manner; as, for instance, Maudslay and Field's or Ravenhill and Salkeld's, return-rod engines. But with direct-acting engines the opposite to this takes place; for with these the bottom diagram is superior to the top. We will first explain the cause of this difference in the case of direct-acting engines. To make the case simpler, let us suppose the lap to be fitted on the steam side of the slides, so as to cut of the steam when the crank has gone through 90° from the top and bottom centres respectively. Put the piston AB at half-stroke; CD being a section of the cylinder: and let OE, EF be the corresponding positions of the crank and con-



necting-rod; the crank making necessarily a small acute angle, EOG, *below* OG: and consequently the steam will not, by our supposition, be cut off till the crank has gone through the angle OEG, or until the piston has risen into some position HK above the middle of the stroke; the distance DK, therefore, will be performed by full steam, and the remaining distance KP by expansive steam. And therefore the diagram for the up-stroke will be fairly represented by a figure such as $MNIPD$. Similarly, in the down-stroke the diagram will be represented by $CHRM$; and therefore in the case we have supposed, viz., when the steam is cut off after 90° have been performed, the bottom diagram is better than the top. But this supposition was only made to render the explanation more simple; for the same thing will happen if the steam be cut off after any other angle has been performed. The same thing may be represented as follows: Let OB, OB' be the crank in two positions, making the same angle BOA, $B'OC$ with the vertical. Let also BC $B'C'$ be the connecting-rod in its two corresponding positions of the connecting-rod with centres OCC'; describe the arcs AB, $B'C$, BE, $B'E'$. Then it will be found in all cases that the distance CD through which the connecting-rod has descended $= AE$ (the difference of the versines of the arcs AB and BE); but that $C'F$, the space through which the point C' has been raised, $=E'C$ (the sum of the versines of the arcs $B'E'$ and $B'C$).

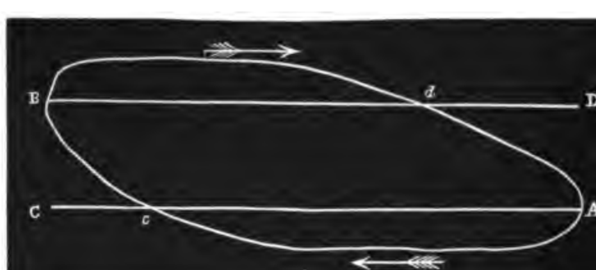


Moreover, it is clear that in side-lever and return-rod engines we must reverse the conclusions to which we have

here arrived, because as the crank is descending, the piston is rising instead of falling with the crank.

A diagram representing the relative motions of the slide and piston at every part of the stroke.

If we shut off all ingress of steam to the Indicator by means of the stop-cock *m* (see Plate), and connect the piston of this instrument with any of the moving parts of the engine, it will give a representation of the motion of that part. Let, therefore, the Indicator-piston be connected, by means of fair-leaders, or otherwise, with the slide; all vertical ascending motions of the pencil will represent the motions of the slide (being upwards or downwards, according to circumstances). Again, let the Indicator-barrel be connected by means of its pulley *D* with the cross-head of the engine, as in all ordinary cases. It will hence follow, that horizontal motions of the pencil will represent the motions of the steam-piston; and consequently, the curve traced out will represent the relative motions of the slide and piston. The figure will be of an elliptical appearance, as in the accompanying tracing,



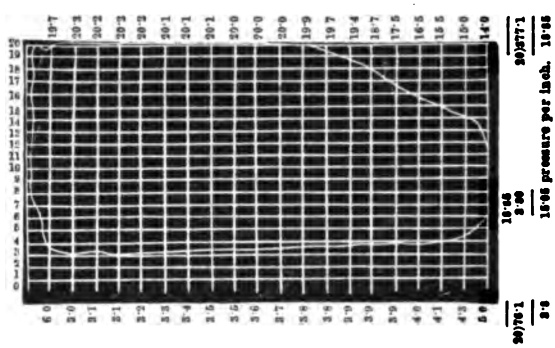
which is one of these curves on a reduced scale: the pencil being supposed to move in the direction of the arrows. The chief information to be gained from this curve is de-

rived from the means it gives us of ascertaining at what portion of the stroke the steam is cut off. For that purpose, let the engine be brought to rest, when on its upper centre, and make a mark (as at A) where the pencil is stationary; and again, make a mark (as at B) where the pencil remains when the engine is on the bottom centre. Through A and B draw horizontal lines, AC, BD, the whole length of the figure. Then AC representing the down-stroke, Ac will give us that *part* of the down-stroke performed before the steam is cut off; and, similarly, Bd will represent the same portion of the up-stroke. This is evident, because neglecting the *lead* of the slide, and supposing it to be correctly set, it begins to open at A and closes at c, opens again at B and closes at d.

To find, separately, the value to be given to the steam and vacuum pressures.

To obtain this, we must get the *actual* pressure, and not the difference of pressure between the steam and vacuum lines. And therefore we might measure the height of the spaces above the atmospheric line, and the depth of the vacuum below it. But, in regard to the steam-line, a difficulty has to be surmounted which would not easily be got over by practical men unaccustomed to analytical investigations. It is this: that part of the steam-line is usually above the atmospheric line, and part below it; and the result of the one must be subtracted from the results of the other. This is more particularly to be noticed in cases where the engine is working expansively, and a great portion of the steam line is in consequence below the atmospheric line. The following suggestion will, however, get over the difficulty: and consider the

atmospheric line, as in the following figure, to be 15 lbs. (which is its actual pressure), and reckoning downwards, call the lines below it 14, 13, etc., till we come to 3, 2, 1,



0: the line marked 0 we will assume as that line from which the pressures are measured, and both the steam and vacuum line will be above this new zero line; and the actual pressure of each will, by these means, be ascertained, and not the relative pressure, as compared with that of the atmosphere. In the preceding diagram this second method of computation has been performed; the numbers on the left-hand side beginning from the absolute zero, and the figures along the top and bottom of the curve giving the steam and vacuum pressures respectively. The mean of the steam-pressure is 18·85 lbs., and of the vacuum 3·8 lbs. The difference is 15·05, as we obtained before.

To estimate the work done in a single stroke of the engine.

Let us suppose the piston to be descending; then the steam-pressure acts above the piston, and the vacuum-pressure below the piston; that is to say, the steam-pressure must be got from the top diagram, and the vacuum-pressure from the bottom diagram; and we must, there-

fore, make use of the method proposed in the answer to the last question. Thus, to obtain the mean pressure during the down-stroke, take the steam-pressure from the top diagram, and the vacuum-pressure from the bottom diagram, and subtract the latter from the former. Again, to obtain the pressure during the up-stroke, take the *vacuum*-pressure obtained from the *top* diagram, from the *steam*-pressure got from the *bottom* diagram. This is the only correct method of arriving at the work done during the down and up strokes respectively.

Method of employing the Indicator for ascertaining the quantity of water evaporated by a boiler.

Fix on any convenient part of the steam-line between that point where the steam is cut off and the opening is made to the condenser; that is to say, between the points *C* and *D* of the diagram, p. 15. Observe, by counting the vertical spaces, what proportion the portion of the stroke, as far as this point, bears to the whole length of the stroke. Notice also the pressure of the steam at this point. Then we shall have a certain fraction of the cylinder filled at each stroke with steam of a given pressure. If now the cubic contents of the cylinder be determined, and the number of times the cylinder is filled per minute, we shall have the quantity of steam of known pressure supplied to the engine per minute. Thus suppose that in the *Bee* $\frac{9}{10}$ of the cylinder were filled with steam of 15 lbs. pressure; then, since the number of cubic inches in the cylinder twice filled is 15079·6, the number of revolutions being 34 at the time of experiment, the whole number of inches in a minute = 512526·4, $\frac{9}{10} \times 512526{\cdot}4 = 461273{\cdot}76$, and the number of cubic inches of atmospheric steam in an hour = $461273{\cdot}76 \times 60 = 27676425{\cdot}60$. But each inch of

water is supposed to form 1711 cubic inches of steam at the atmospheric pressure, and therefore the number of cubic inches of water evaporated $= \frac{27676425 \cdot 6}{1711} = 16175$; and the number of gallons of water evaporated $= \frac{16175}{277} = 58$ nearly.

Now, if the theory be correct, this should be the quantity of water evaporated from the boiler, due allowance being made for condensation, etc., in the steam-pipe and passages. But this is far from being the case, for the number of gallons actually evaporated by the boiler was ascertained to be 108 gallons in the hour. The reason for this appears evident. From the violence of the ebullition, the steam is in all likelihood not so dry as that on which careful experiments are made, as is frequently made manifest in the boilers that "prime;" so that, even in good boilers, we may conclude that the steam contains much more watery vapor than it would if it were not so rapidly consumed. If so, an inch of water would not under these circumstances form 1711 cubic inches of steam under the atmospheric pressure, and might perhaps form only one-half that quantity, which would be requisite to give the proper number of gallons of evaporated water.

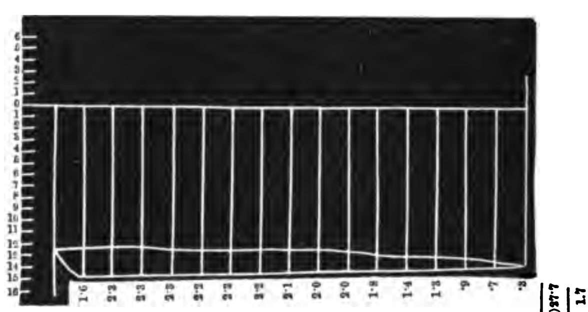
To ascertain the friction of a Steam-engine when working without any load.

If we examine the effect of any machine at work, however simple, we shall find a certain amount of power is requisite to overcome the friction of the engine itself. Divest, for example, a common crane of its chain, or any load that may be upon it, and it will still be found that some force must be applied to give motion to the gearing alone; the amount of force depending on the materials

used, the mode of fitting, and the quantity of gear set in motion. So it is with the Steam-engine. A certain amount of power is required to overcome the friction of all its parts; and in this respect no two engines will be found alike, so much depending on the goodness of the workmanship, and the nice adjustment of the different parts.

Before proceeding with the method of ascertaining the friction of an engine by the Indicator, we would observe, that the greatest care and judgment are requisite in carrying out this experiment; let no one attempt it unless he see his way clearly; and there are many classes of engines in which the experiment ought not to be tried, such as direct acting paddle-engines; indeed, in all unbalanced engines it would be attended with serious risk, by giving the engine enough steam to work it without its load. But it may be carried out satisfactorily and safely in horizontal engines, because their weights and resistances are balanced. The way, however, to proceed is this: the *communication-valve* must first be closed, because the engine requires an exceedingly small quantity of steam to work it when the paddle-wheels are disengaged. Then let the blow-valve be opened, to allow any steam that may happen to be in the steam-pipe to escape. The more the vacuum is vitiated before commencing the experiment, the safer it will be; for there is less liability of injury to the engine when first set in motion. With the engines of H.M.S. *Bee*, it is found necessary to destroy the vacuum, before getting the diagram, by opening the blow-valve, to prevent the engine flying off at too great speed. The throttle-valve must be closed, and the paddles disconnected. After slightly opening the communication and throttle-valves, the slide may be opened gradually and cautiously, to admit the steam to the piston, and the injection must be let on

as carefully as possible. Work the engine a few strokes by hand, and then let it be thrown into gear, and regulate the working by the throttle and communication-valves; the object being to give the engine the same number of revolutions without the paddles as it usually has with them; taking care to have the condenser of the same temperature as in the ordinary working state of the engine.* The Indicator having been previously fixed and adjusted, let a diagram be taken: it will be widely different from that when the load is on. Both the steam-line and vacuum-line will be much below the atmospheric line. The diagram may then be taken off, and divided as in the former case. Let the result of this diagram be worked off in the same manner as the common diagram, and the amount is the work the steam has performed, or in other words, the friction of the unloaded engine. This has been accomplished in the subjoined diagram.



* We would strongly advise the insertion of the bulb of a thermometer in the condenser of every engine, in addition to the barometer-gauge. The bulb must be entirely within the condenser, and the scale (at least that part of it which is above 50° or 60°) outside, in the engine-room. The thermometer chosen for the purpose must be graduated higher than the temperature of the steam in the boiler, otherwise it will burst when the engine is blown through. It must be placed on some part acted on freely by the steam, but free from the splash of the injection-water. When the engine is free from air it will then serve as a most delicate test of the vacuum. The temperature preserved should be about 100°.

This is what is commonly subtracted from the gross result obtained under ordinary circumstances, and denominated friction; but it is manifest that it is much less than the actual friction of the engine when turning the wheels; for the friction of every machine increases with its load; and, moreover, the injection water, etc., raised by the air-pump, increases likewise, and all this goes under the head of friction. The friction of large engines is less in proportion than that of smaller ones. In large engines it is usual to allow 1 lb. on the square inch of the piston for friction, and in small engines from 1·5 to 2 lbs.; and in most cases it would be better, except as a matter of experiment, to trust to this than to attempt the difficulty of ascertaining it.

The diagram does not necessarily return into itself, and form a closed figure.

This only happens because the Indicator-barrel contains the spring which, as has been stated, draws back the barrel directly the string relaxes. But we can by a different arrangement produce a figure of some value, in which the curve proceeds continuously in one direction, and which, therefore, we shall call the "continuous diagram." Let the spring, fitted to the traversing cylinder for bringing it back, be taken out, and also the stop that prevents the cylinder from going too far; because our object is to let the barrel revolve freely. The clasp, by which the paper is usually secured, must also be taken off, and the paper must be secured by turning it over the top of the cylinder, and be folded in such a manner that the pressure of the pencil will help to keep it down. Let now some part of the engine be selected where a double pulley may be fitted to revolve one groove of the pulley having about the same

diameter as the pulley attached to the barrel, and the other to the diameter of the paddle-shaft. A string must be passed round this latter pulley and the shaft, and they will revolve in the same time. Another string must be passed round the pulley of the barrel and the smaller of the two pulleys; and then the Indicator-barrel will revolve nearly in the same time as the engine shaft. And if we suppose the shaft to be revolving uniformly, which it will be nearly, especially where there are two engines, the barrel will have a uniform motion in one direction. If the pencil be put to the paper, as in ordinary cases, when the Indicator-piston is at the lowest, it will commence tracing its curve. It should be allowed to remain for one entire revolution, and longer if convenient, provided one line do not interfere with the other in going twice over the paper.

The chief practical utility of the continuous diagram is, that it serves to show *the rate* at which the steam-pressure increases or decreases. Looking at the continuous diagram, Plate I. Fig. 2, we observe that the steam-pressure does not arrive at its maximum instantaneously, as many suppose, and as the normal diagram, p. 15, would lead us to believe. The vacuum commences at D and continues to E, the cushioning from E to A; the fresh steam enters at A, and causes the pencil to rise till it reaches its highest at B.

To explain why the first diagram in p. 41 *is rounded at the upper left-hand corner.*

If we examine this diagram by any of the previous tests, we shall find it presents a difficulty not easily surmounted. For in all former cases we can only correct a defect in this corner at the expense of the lower left-hand and the upper right-hand corners. As the Indicator persisted in giving

this outline, and all attempts according to the foregoing principles (by altering the set of the slides, etc.) failed, it was at length proposed to examine the steam-piston itself; and accordingly, steam was let in at the lower port, and the cock of the grease-cup opened, when it was discovered that the piston was not steam-tight in the cylinder; and therefore, although when the engine was working the first impulse of the steam sufficed to drive the pencil up, yet as soon as the piston had got into motion, the escape of steam by leakage did not allow the pencil to rise so rapidly as it otherwise would have done. This roundness is also observable if the speed of the piston be much increased.

Indicator diagram taken when the engine is worked without condensation of the steam.

It is evident that no part of the diagram can be below the atmospheric line, for the pressure can never be less than that of the atmosphere. And since the steam has not a free escape into the air, but is obliged to force open the foot-valve and delivery-valve, and make its way through the air-pump bucket, the resistance it meets with will cause the pressure to be greater than that of the atmos-

phere. Engines whose steam-pressure is not considerably greater than that of the atmosphere cannot be worked on the high-pressure principle. The foregoing diagram was taken from H.M.S. *Bee*, whose boiler-pressure at that

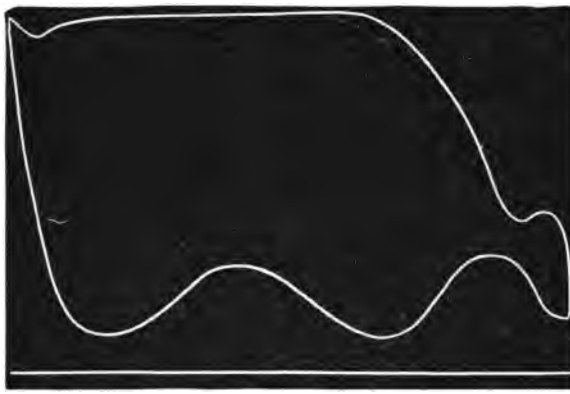
time was 7 lbs. In high-pressure engines the diagram will be similar to the above; because the steam, having to escape by the blast-pipe, is pent up, and causes the lower part of the diagram to be above the atmospheric line. In general, the steam and vacuum line must be worked out separately, by the plan proposed in p. 49; for it will be observed, that the lines intersect each other in the diagram. The Indicator for high-pressure engines should be made expressly for the purpose; the scale of pounds should have a higher range, but need not go below the atmospheric line.

This curve presents a singular appearance, from the steam and exhaust line intersecting. Since the cushioning begins at the usual place, that is to say, at the same part of the stroke as when used as a low-pressure engine, the steam pent up on the exhaust side, and commencing with a greater pressure than that of the atmosphere, soon surpasses that of the boiler, so that when the port begins to open, the pressure suddenly falls. Again when the entering steam is cut off, the pressure gradually falls, and before the end of the stroke it is less than that of the eduction; and when open again to exhaust, steam enters from the condenser, and the loop of the right-hand corner is formed.

High-pressure diagram.

The accompanying diagram, taken from a high-pressure engine, exhibits practically what we were led to expect in the foregoing article. The vibrations of the spring of the Indicator cause the curve to be distorted, and probably the lower portion is more sensibly affected from another circumstance which we will explain. In these engines, since each engine discharges into one common blast-pipe, there

will be a reflex action of the waste steam from one engine tending to resist the escape of that from the other. The



effect thus produced is more sensibly manifested when the blast-pipe terminates in a contracted orifice or nozzle.

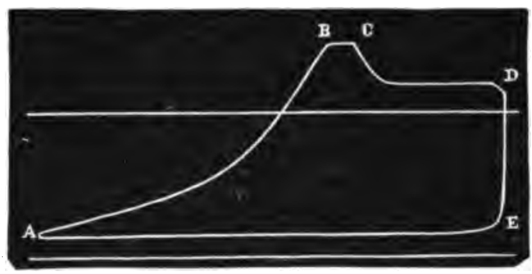
Diagram obtained when there was no load on the safety-valve.

The safety-valve of the boiler was kept open so as to reduce the steam to the pressure of the atmosphere, and the accompanving series of diagrams was taken at the

various grades of expansion. It differs from that exhibited in the diagram obtained when the injection-water was shut off, in this respect, viz., that the whole of the diagram in the former case was above the atmospheric line, whereas in this all of them are below that line.

Air-pump diagram.

The accompanying diagram is the result of connecting the Indicator with the cylinder-cover of the air-pump of an engine. It was taken by Mr. Eames, chief-engineer,



H.M.S. *Inflexible*, and was kindly given by him to the authors. To explain it, let us suppose the pencil to be at *A* when the bucket of the air-pump is at the bottom of its stroke, at which time there will be nearly a vacuum in the air-pump cylinder. As the bucket is raised with the water which it carries, the superincumbent steam becomes compressed, consequently the pencil rises, as in the curve *AB*. When at some point, *B* the delivery-valve is forced open, and the pent-up steam makes its escape; after which the pencil drops slightly at *C*, and exhibits the constant pressure of the water as it goes off by the waste-water pipe. On the descent of the bucket, since the steam has disappeared, the pencil suddenly falls through *DE*, and continues its course to *A* horizontally.

THE DYNAMOMETER.

THIS instrument has been introduced into some screw-vessels, for the purpose of enabling the engineer to record the exact amount of pressure given off by the screw-shaft, and, consequently, the force the engine, by means of this instrument, is exerting to propel the ship. It is merely a lever, or a combination of levers; the shaft pressing near the fulcrum, and the farther end of the lever, or combination, being attached to a Salter's spring balance. In the diagram, Plate I. Fig. 3, *AB* is the screw-shaft pressing as it revolves against a movable pin which is contained in the plomer-block at *C*, and can slide freely backwards and forwards; *DE* is the lever, having the fulcrum at *D*; the pin at *C* presses against a knife-edge on the lever, as is seen in the figure. The rod *EF* is connected with the spring of a Salter's balance, which cannot be seen in the figure, but is concealed from sight by the cylindrical barrel *IK*; *F* is also attached to the rod *GH*. This rod, as we perceive, has several grooves in it, so that the small fork carrying the pencil (*p*) may be brought in contact with more than one part of the barrel in succession if desirable.

The barrel is made to revolve by means of a strap *ab*, connecting it with the screw-shaft; and it will be seen by the figure, that there are pulleys of different sizes con-

nected with the bulk-head at *M*, and the shaft at *N*, by which the motion of the cylinder can be regulated, and be made quicker or slower at pleasure. The curve will evidently be somewhat similar to the ***continuous Indicator diagram*** (Plate I. Fig. 2), consisting of a series of undulations according to the force of the steam and its action on the propeller. A zero-line must be got, as in the case of the Indicator. When the Dynamometer is applied to large engines, the levers can be relieved of the pressure of the shaft; and this being accomplished, the index of the spring-balance will stand at 0, when the zero-line may be traced. The balance will also give the scale of pounds. After the diagram is traced, draw a series of equidistant lines at right angles to the zero-line, as in Plate I. Fig. 4, which represents a Dynamometer diagram taken on board *Rattler* during her trial with *Alecto*, the dimensions being reduced one-half. The distance between the curve and zero-line must be measured and compared with the scale of pounds on the balance. Let this be registered on the diagram in its proper space. These must be added up, and the sum be divided by the number of spaces taken into account. Thus we shall obtain the mean force of the lever on the spring of the balance; let this be multiplied again by the *leverage* of the Dynamometer, and the result will be the pressure of the screw-shaft on the Dynamometer, and therefore on the vessel.* To obtain the leverage, if the lever be compound, multiply together all the long arms (measuring from the fulcrum),

* A doubt has been expressed by some whether this is really the force exerted by the shaft on the vessel, on account of the shaft acting on a lever that yields to its force; but independently of the fact, that none of the thrust can be lost, it is clear that the thrust at *C* is equal to the thrust at *D* and that at *E*, and these are the two forces acting on the vessel.

and divide the product by all the short arms multiplied together (measuring also from the fulcrum).

Method of obtaining the effective horse-power of an engine by the Dynamometer.

Having found the number of *pounds* pressure exerted by the screw-shaft, multiply it by the speed of the ship in knots, and the product by 6080 (the number of feet in a knot); then divide the result by 60 (the number of minutes in an hour), and by 33,000, and the quotient will be the horse-power.

Or the work may be shortened thus:

Multiply the number of pounds pressure by the speed of the ship in knots, as before, and this product by ·00307, and the product gives the horse-power.

This, it will be observed, is the *effective* horse-power after making allowance for friction and loss by useless resistance.

The diagram before referred to will elucidate the process of working out the result. This was taken simultaneously with two others; and the mean of the three pressures was 41·309 lbs. Multiplying by the power of the system of levers, the result was 8086·4 lbs. (the pressure exerted by the screw-shaft).

The speed of the ship was 9·893 knots.

Hence $8086{\cdot}4 \times 9{\cdot}893 = 79998{\cdot}7$.

And $79998 \times {\cdot}00307 = 245$ nearly; the horse-power required.

The horse-power by Indicator at the same time was 465·6, showing a loss of 220·6 by friction, resistance, etc.

PRESSURES OF STEAM, AND THE CORRESPONDING TEMPERATURES AND RELATIVE VOLUMES.

Pressure in lbs. per square inch.	Temperature by Fahrenheit.	Relative volume.	Pressure in lbs. per square inch.	Temperature by Fahrenheit.	Relative volume.	Pressure in lbs. per square inch.	Temperature by Fahrenheit.	Relative volume.
1	103·0	20911	25	240·9	1043	49	281·4	564
2	126·0	10890	26	243·2	1006	50	282·7	554
3	141·0	7446	27	245·3	972	51	284·0	543
4	152.2	5690	28	247·4	939	52	285·2	533
5	161·4	4620	29	249·4	910	53	286·4	525
6	169·2	3899	30	251·4	882	54	287·6	516
7	175·9	3378	31	253·3	856	55	288·8	507
8	182·0	2984	32	255·2	832	56	290·0	499
9	187·4	2675	33	257·1	809	57	291·2	492
10	192·4	2426	34	258·9	787	58	292·4	484
11	197·0	2222	35	260·6	766	59	293·6	476
12	201·3	2050	36	262·3	747	60	294·8	468
13	205·3	1903	37	264·0	728	61	295·9	462
14	209·0	1777	38	265·6	711	62	297·0	455
15	212·9	1669	39	267·2	694	63	298·1	448
16	216·3	1573	40	268·8	678	64	299·2	442
17	219·6	1488	41	270·2	663	65	300·2	436
18	222·7	1411	42	271·7	649	66	301·2	430
19	225·6	1343	43	273·2	635	67	302·3	424
20	228·4	1281	44	274·6	622	68	303·3	418
21	231·1	1225	45	276·0	609	69	304·3	413
22	233·8	1173	46	277·4	597	70	305·3	407
23	236·3	1126	47	278·8	585			
24	238·6	1083	48	280·1	574			

AREAS OF CIRCLES OF GIVEN DIAMETERS.

DIAM.	AREA.	DIAM.	AREA.	DIAM.	AREA.
20 in.	314·1593	25 in.	490·8739	30 in.	706·8583
1/8	318·0985	1/8	495·7949	1/8	712·7611
1/4	322·0623	1/4	500·7404	1/4	718·6884
3/8	326·0507	3/8	505·7106	3/8	724·6403
1/2	330·0636	1/2	510·7052	1/2	730·6167
5/8	334·1011	5/8	515·7244	5/8	736·6176
3/4	338·1630	3/4	520·7681	3/4	742·6430
7/8	342·2496	7/8	525·8364	7/8	748·6932
21 in.	346·3606	26 in.	530·9292	31 in.	754·7676
1/8	350·4962	1/8	536·0465	1/8	760·8668
1/4	354·6564	1/4	541·1884	1/4	766·9904
3/8	358·8412	3/8	546·3549	3/8	773·1387
1/2	363·0503	1/2	551·5459	1/2	779·3113
5/8	367·2842	5/8	556·7615	5/8	785·5086
3/4	371·5424	3/4	562·0015	3/4	791·7304
7/8	375·8253	7/8	567·2662	7/8	797·9768
22 in.	380·1327	27 in.	572·5553	32 in.	804·2477
1/8	384·4646	1/8	577·8690	1/8	810·5432
1/4	388·8212	1/4	583·2072	1/4	816·8632
3/8	393·2023	3/8	588·5701	3/8	823·2078
1/2	397·6078	1/2	593·9574	1/2	829·5768
5/8	402·0379	5/8	599·3693	5/8	835·9705
3/4	406·4926	3/4	604·8057	3/4	842·3886
7/8	410·9719	7/8	610·2667	7/8	848·8314
23 in.	415·4756	28 in.	615·7522	33 in.	855·2986
1/8	420·0039	1/8	621·2623	1/8	861·7904
1/4	424·5568	1/4	626·7968	1/4	868·3068
3/8	429·1343	3/8	632·3561	3/8	874·8477
1/2	433·7361	1/2	637·9397	1/2	881·4139
5/8	438·3626	5/8	643·5480	5/8	888·0030
3/4	443·0137	3/4	649·1807	3/4	894·6176
7/8	447·6892	7/8	654·8381	7/8	901·2567
24 in.	452·3893	29 in.	660·5199	34 in.	907·9203
1/8	457·1140	1/8	666·2264	1/8	914·6084
1/4	461·8632	1/4	671·9572	1/4	921·3211
3/8	466·6370	3/8	677·7128	3/8	928·0584
1/2	471·4352	1/2	683·4928	1/2	934·8202
5/8	476·2581	5/8	689·2974	5/8	941·6066
3/4	481·1055	3/4	695·1265	3/4	948·4174
7/8	485·9775	7/8	700·9802	7/8	955·2529

DIAM.	AREA.	DIAM.	AREA.	DIAM.	AREA.
35 in.	962·1127	41 in.	1320·2543	47 in.	1734·9445
1/8	968·9973	1/8	1328·3170	1/8	1744·1852
1/4	975·9063	1/4	1336·4041	1/4	1753·4505
3/8	982·8400	3/8	1344·5159	3/8	1762·7304
1/2	989·7980	1/2	1352·6520	1/2	1772·0546
5/8	996·7807	5/8	1360·8129	5/8	1781·3936
3/4	1003·7879	3/4	1368·9981	3/4	1790·7569
7/8	1010·8197	7/8	1377·2080	7/8	1800·1450
36 in.	1017·8760	42 in.	1385·4424	48 in.	1809·5574
1/8	1024·9568	1/8	1393·7013	1/8	1818·9944
1/4	1032·0622	1/4	1401·9848	1/4	1828·4560
3/8	1039·1922	3/8	1410·2929	3/8	1837·9322
1/2	1046·3467	1/2	1418·6254	1/2	1847·4528
5/8	1053·5257	5/8	1426·9826	5/8	1856·9881
3/4	1060·7293	3/4	1435·3642	3/4	1866·5478
7/8	1067·9575	7/8	1443·7705	7/8	1876·1322
37 in.	1075·2101	43 in.	1452·2012	49 in.	1885·7410
1/8	1082·4873	1/8	1460·6565	1/8	1895·3744
1/4	1089·7890	1/4	1469·1364	1/4	1905·0323
3/8	1097·1154	3/8	1477·6310	3/8	1914·7150
1/2	1104·4662	1/2	1486·1697	1/2	1924·4218
5/8	1111·8416	5/8	1494·7234	5/8	1934·1534
3/4	1119·2415	3/4	1503·3012	3/4	1943·9095
7/8	1126·6660	7/8	1511·9038	7/8	1953·6902
38 in.	1134·1149	44 in.	1520·5308	50 in.	1963·4954
1/8	1141·5885	1/8	1529·1825	1/8	1973·3251
1/4	1149·0866	1/4	1537·8587	1/4	1983·1794
3/8	1156·6083	3/8	1546·5475	3/8	1993·0583
1/2	1164·1564	1/2	1555·2847	1/2	2002·9617
5/8	1171·7282	5/8	1564·0346	5/8	2012·8897
3/4	1179·3244	3/4	1572·8089	3/4	2022·8421
7/8	1186·9453	7/8	1581·6079	7/8	2032·8172
39 in.	1194·5906	45 in.	1590·4313	51 in.	2042·8206
1/8	1202·2605	1/8	1599·2777	1/8	2052·8467
1/4	1209·9550	1/4	1608·1518	1/4	2062·8974
3/8	1217·6740	3/8	1617·0390	3/8	2072·9727
1/2	1225·4175	1/2	1625·9705	1/2	2083·0723
5/8	1233·1856	5/8	1634·9267	5/8	2093·1966
3/4	1240·9782	3/4	1643·8874	3/4	2103·3554
7/8	1248·7954	7/8	1652·8827	7/8	2113·5188
40 in.	1256·6370	46 in.	1661·9025	52 in.	2123·7166
1/8	1264·5032	1/8	1670·9469	1/8	2133·9390
1/4	1272·3941	1/4	1680·0158	1/4	2144·1861
3/8	1280·3094	3/8	1689·0993	3/8	2154·4576
1/2	1288·2493	1/2	1698·2272	1/2	2164·7537
5/8	1296·2138	5/8	1707·3698	5/8	2175·0744
3/4	1304·2027	3/4	1716·5368	3/4	2185·4195
7/8	1312·2163	7/8	1725·7284	7/8	2195·7893

DIAM.	AREA.	DIAM.	AREA.	DIAM.	AREA.
53 in	2206·1834	59 in.	2733·9710	65 in.	3318·3072
⅛	2216·6022	⅛	2745·5681	⅛	3331·0822
¼	2227·0456	¼	2757·1893	¼	3343·8818
⅜	2237·5132	⅜	2768·8355	⅜	3356·7059
½	2248·0059	½	2780·5059	½	3369·5545
⅝	2258·5229	⅝	2792·2010	⅝	3382·4277
¾	2269·0644	¾	2803·9205	¾	3395·3253
⅞	2279·6305	⅞	2815·6647	⅞	3408·2476
54 in.	2290·2110	60 in.	2827·4334	66 in.	3421·1944
⅛	2300·8362	⅛	2839·2266	⅛	3434·1657
¼	2311·4759	¼	2851·0444	¼	3447·1616
⅜	2322·1392	⅜	2862·8868	⅜	3460·1820
½	2332·8289	½	2874·7536	½	3473·2270
⅝	2343·5423	⅝	2886·6450	⅝	3486·3966
¾	2354·2801	¾	2898·5610	¾	3499·3906
⅞	2365·0426	⅞	2910·5016	⅞	3512·5093
55 in.	2375·8294	61 in.	2922·4666	67 in.	3525·6524
⅛	2386·6411	⅛	2934·4562	⅛	3538·8201
¼	2397·4770	¼	2946·4703	¼	3552·0123
⅜	2408·3377	⅜	2958·5091	⅜	3565·2292
½	2419·2227	½	2970·5722	½	3578·4704
⅝	2430·1775	⅝	2982·6600	⅝	3591·7363
¾	2441·0666	¾	2994·7723	¾	3605·0267
⅞	2452·0254	⅞	3006·9092	⅞	3618·3417
56 in.	2463·0086	62 in.	3019·0705	68 in.	3631·6811
⅛	2474·0145	⅛	3031·2560	⅛	3645·0451
¼	2485·0489	¼	3043·4670	¼	3658·4337
⅜	2496·1059	⅜	3055·7021	⅜	3671·8469
½	2507·1873	½	3067·9616	½	3685·2845
⅝	2518·2934	⅝	3080·2458	⅝	3698·7468
¾	2529·4239	¾	3092·5544	¾	3712·2335
⅞	2540·5781	⅞	3104·8877	⅞	3725·7450
57 in.	2551·7586	63 in.	3117·2453	69 in.	3739·2807
⅛	2562·9629	⅛	3129·6273	⅛	3752·8411
¼	2574·1916	¼	3142·0344	¼	3766·4260
⅜	2585·4450	⅜	3154·4659	⅜	3780·0356
½	2596·7227	½	3166·9217	½	3793·6695
⅝	2608·0251	⅝	3179·4022	⅝	3807·3281
¾	2619·3520	¾	3191·9072	¾	3821·0112
⅞	2630·7035	⅞	3204·4368	⅞	3834·7189
58 in.	2642·0794	64 in.	3216·9909	70 in.	3848·4510
⅛	2653·4800	⅛	3229·5695	⅛	3862·2077
¼	2664·9051	¼	3242·1707	¼	3875·9890
⅜	2676·3549	⅜	3254·8005	⅜	3889·7948
½	2687·8289	½	3267·4527	½	3903·6252
⅝	2699·3277	⅝	3280·1296	⅝	3917·4802
¾	2710·8508	¾	3292·8309	¾	3931·3596
⅞	2722·3988	⅞	3305·5566	⅞	3945·2636

DIAM.	AREA.	DIAM.	AREA.	DIAM.	AREA.
71 in.	3959·1921	77 in.	4656·6257	83 in.	5410·6079
⅛	3973·1452	⅛	4671·7569	⅛	5426·9172
¼	3987·1229	¼	4686·9126	¼	5443·2511
⅜	4001·1252	⅜	4702·0929	⅜	5459·6096
½	4015·1518	½	4717·2977	½	5475·9923
⅝	4029·2031	⅝	4732·5271	⅝	5492·3998
¾	4043·2788	¾	4747·7810	¾	5508·8318
⅞	4057·3884	⅞	4763·0595	⅞	5525·2884
72 in.	4071·5041	78 in.	4778·3624	84 in.	5541·7694
⅛	4085·6532	⅛	4793·6890	⅛	5558·2751
¼	4099·8275	¼	4809·0420	¼	5574·8053
⅜	4114·0260	⅜	4824·4187	⅜	5591·3600
½	4128·2490	½	4839·8198	½	5607·9392
⅝	4142·4967	⅝	4855·2455	⅝	5624·5430
¾	4156·7689	¾	4870·7958	¾	5641·1714
⅞	4171·0656	⅞	4886·1707	⅞	5657·8236
73 in.	4185·3868	79 in.	4901·6669	85 in.	5674·5017
⅛	4199·7326	⅛	4917·1938	⅛	5691·2037
¼	4214·1029	¼	4932·7423	¼	5707·9302
⅜	4228·4979	⅜	4948·3154	⅜	5724·6814
½	4242·9171	½	4963·9127	½	5741·4569
⅝	4257·3611	⅝	4979·5310	⅝	5758·2631
¾	4271·8296	¾	4995·1814	¾	5775·0818
⅞	4286·3227	⅞	5010·8526	⅞	5791·9311
74 in.	4300·8404	80 in.	5026·5482	86 in.	5808·8048
⅛	4315·3826	⅛	5042·2785	⅛	5825·7032
¼	4329·9492	¼	5058·0133	¼	5842·6260
⅜	4344·5405	⅜	5073·7826	⅜	5859·5735
½	4359·1563	½	5089·5764	½	5876·5454
⅝	4373·7967	⅝	5105·3948	⅝	5893·5420
¾	4388·4613	¾	5121·2378	¾	5910·5630
⅞	4403·1508	⅞	5137·1054	⅞	5927·6087
75 in.	4417·8647	81 in.	5152·9973	87 in.	5944·6787
⅛	4432·6032	⅛	5168·9140	⅛	5961·7734
¼	4447·3662	¼	5184·8551	¼	5978·8926
⅜	4462·1539	⅜	5200·8208	⅜	5996·0365
½	4476·9659	½	5216·8109	½	6013·2047
⅝	4491·8026	⅝	5232·8258	⅝	6030·3975
¾	4506·6637	¾	5248·8650	¾	6047·6149
⅞	4521·5495	⅞	5264·9289	⅞	6064·8569
76 in.	4536·4598	82 in.	5281·0172	88 in.	6082·1234
⅛	4551·3946	⅛	5297·1302	⅛	6099·4145
¼	4566·3540	¼	5313·2677	¼	6116·7300
⅜	4581·3379	⅜	5329·4297	⅜	6134·0702
½	4596·3464	½	5345·6162	½	6151·4349
⅝	4611·3895	⅝	5361·8273	⅝	6168·8240
¾	4626·4370	¾	5378·0630	¾	6186·2377
⅞	4641·5192	⅞	5394·3233	⅞	6203·6751

DIAM.	AREA.	DIAM.	AREA.	DIAM.	AREA.
89 in.	6221·1389	93 in.	6792·9087	97 in.	7389·8113
$\frac{1}{8}$	6238·6263	$\frac{1}{8}$	6811·1814	$\frac{1}{8}$	7408·8695
$\frac{1}{4}$	6256·1382	$\frac{1}{4}$	6829·4788	$\frac{1}{4}$	7427·9522
$\frac{3}{8}$	6273·6746	$\frac{3}{8}$	6847·8007	$\frac{3}{8}$	7447·0595
$\frac{1}{2}$	6291·2356	$\frac{1}{2}$	6866·1471	$\frac{1}{2}$	7466·1913
$\frac{5}{8}$	6308·8212	$\frac{5}{8}$	6884·5182	$\frac{5}{8}$	7485·3478
$\frac{3}{4}$	6326·4313	$\frac{3}{4}$	6902·9135	$\frac{3}{4}$	7504·5285
$\frac{7}{8}$	6344·0660	$\frac{7}{8}$	6921·3336	$\frac{7}{8}$	7523·7340
90 in.	6361·7251	94 in.	6939·7782	98 in.	7542·9640
$\frac{1}{8}$	6379·4069	$\frac{1}{8}$	6958·2474	$\frac{1}{8}$	7562·2186
$\frac{1}{4}$	6397·1171	$\frac{1}{4}$	6976·7410	$\frac{1}{4}$	7581·4976
$\frac{3}{8}$	6414·8499	$\frac{3}{8}$	6995·2593	$\frac{3}{8}$	7600·8012
$\frac{1}{2}$	6432·6073	$\frac{1}{2}$	7013·8019	$\frac{1}{2}$	7620·1293
$\frac{5}{8}$	6450·3893	$\frac{5}{8}$	7032·3693	$\frac{5}{8}$	7639·4810
$\frac{3}{4}$	6468·1954	$\frac{3}{4}$	7050·9612	$\frac{3}{4}$	7658·8593
$\frac{7}{8}$	6486·0265	$\frac{7}{8}$	7069·5777	$\frac{7}{8}$	7678·2610
91 in.	6503·8821	95 in.	7088·2184	99 in.	7697·6874
$\frac{1}{8}$	6521·7622	$\frac{1}{8}$	7106·8839	$\frac{1}{8}$	7717·1383
$\frac{1}{4}$	6539·6669	$\frac{1}{4}$	7125·5799	$\frac{1}{4}$	7736·6137
$\frac{3}{8}$	6557·5962	$\frac{3}{8}$	7144·2886	$\frac{3}{8}$	7756·1137
$\frac{1}{2}$	6575·5498	$\frac{1}{2}$	7163·0276	$\frac{1}{2}$	7775·6382
$\frac{5}{8}$	6593·5281	$\frac{5}{8}$	7181·7914	$\frac{5}{8}$	7795·1873
$\frac{3}{4}$	6611·5308	$\frac{3}{4}$	7200·5794	$\frac{3}{4}$	7814·7608
$\frac{7}{8}$	6629·5582	$\frac{7}{8}$	7219·3921	$\frac{7}{8}$	7834·3590
92 in.	6647·6100	96 in.	7238·2295	100 in.	7853·9816
$\frac{1}{8}$	6665·6865	$\frac{1}{8}$	7257·0914		
$\frac{1}{4}$	6683·7875	$\frac{1}{4}$	7275·9777		
$\frac{3}{8}$	6701·9131	$\frac{3}{8}$	7294·8886		
$\frac{1}{2}$	6720·0630	$\frac{1}{2}$	7313·8240		
$\frac{5}{8}$	6738·2377	$\frac{5}{8}$	7332·7841		
$\frac{3}{4}$	6756·4368	$\frac{3}{4}$	7351·7686		
$\frac{7}{8}$	6774·6605	$\frac{7}{8}$	7370·7777		

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